INVESTIGATING SCIENCE WITH CHILDREN / VOLUME 5

ENERGY IN WAVES

National Science Teachers Association

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INVESTIGATING SCIENCE WITH CHILDREN

VOLUME 5

ENERGY IN WAVES

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Produced as a Joint Project of
National Science Teachers Association and
National Aeronautics and Space Administration

Published by
TEACHERS PUBLISHING CORPORATION
Darien, Connecticut

INVESTIGATING SCIENCE WITH CHILDREN SERIES

Volume 1 LIVING THINGS

Volume 2 THE EARTH

Volume 3 ATOMS AND MOLECULES

Volume 4 MOTION

Volume 5 ENERGY IN WAVES

Volume 6 SPACE

The National Science Teachers Association is a department of the National Education Association (NEA) and an affiliate of the American Association for the Advancement of Science (AAAS).

About the cover: Waves spread across the surface of a pond in ever-widening circles from the point at which a rock enters the water. These waves are symbolic of the many forms of energy that travel in waves.

Printed in the United States of America
Library of Congress Catalog Card No. 64-22845

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About the INVESTIGATING SCIENCE WITH CHILDREN Series

These six handbooks for the teaching of science in the elementary school have the distinguished sponsorship of two leading groups concerned with the improvement of science teaching: NSTA (The National Science Teachers Association) and NASA (The National Aeronautics and Space Administration). Initiated by NSTA, the series received technical and financial assistance from NASA. The six authors were carefully chosen by NSTA and NASA from among leading science educators in the United States and Canada. The series has been carefully planned, developed, and edited over a period of two years. It updates and replaces the widely successful SCIENCE TEACHING TODAY series by Dr. Guy Bruce, published by NSTA in 1950.

General approach and philosophy. As they planned this series of books, members of the writing team were concerned with the following questions: What are some things we can or should do to help teachers as they investigate the world of science with children? In what direction should we move? How can we incorporate into our writings the processes and content of science, the fostering of creativity in children, provisions for children's varying abilities?

The age and culture in which we live demand that children in the elementary schools have a variety of real science experiences that lead them to an understanding of the world about them. Through a variety of science experiences, each individual will come to understand and to use scientific processes and skills, as well as to acquire the specific science learnings that will help him live intelligently.

Since each book in the series is concerned with one area of science and moves from simple concepts to more complex ones within each chapter, *each* teacher, at any grade level, will find that *all* the books have materials that she can use in her teaching.

Question-discovery approach used. Throughout each book, questions are used in several different ways. At the beginning of each chapter is a list of questions that children of different ages might ask. Answers to these questions and others are found when the children become involved in doing the Activities of the specific chapter. Other questions, with answers containing the science information given in parentheses for the teacher, are included within each Activity to help teachers as they guide the children's learning. More questions are listed later, as open-end Activities to be used with those children who may wish to make further investigations.

Organization keyed to varying abilities. To provide for varying abilities of the children in a group and at different grade levels, as well as to make possible a developmental approach to concept formation, the Activities and learnings are purposely not "graded," but are designated by the following symbols: *x* for those Activities involving beginning learnings; *y* for those Activities requiring more skill and involving several learnings; and *z* for those Activities of considerable difficulty and involving more complex thought patterns. An introduction is included with each Activity, which is merely suggestive and which may give the teacher ideas helpful in challenging children's thinking.

Illustrations and format. All six of the volumes are filled with helpful illustrations that will help the teacher as she directs the children's participation in the Activities. A two-column format allows for easy reading and clear organization, for in-class presentation.

Summaries and references. Each chapter concludes with a summary of the main ideas developed by the author. Throughout each book, cross references are made to Activities and science content found in the other books of the series. At the end of each book there is a list of bibliographical references that contain additional science information.

Scientific accuracy assured. One of the concerns of the writing team was the scientific accuracy of the information appearing in each book. To insure such accuracy, leading scientists who are specialists in their respective fields were asked to read and review the content during the preparation of the manuscripts. Their names appear at the end of this section.

It is hoped that this series of books, INVESTIGATING SCIENCE WITH CHILDREN, will be helpful in providing opportunities for children to use many processes of inquiry —investigating, observing, problem-solving, hypothesizing, experimenting, thinking, checking, analyzing—as they try to find the *what*, *how*, and *why* of the world around them. There are no final answers in these books. Let the series be thought of as a challenge to teachers to further learning.

Acknowledgments. Many people have made this series possible. The authors and series editor wish to express their appreciation to Robert Carleton, Executive Secretary of the National Science Teachers Association, for his confidence in the project and for his many words of encouragement; to Frank Salamon, Specialist in Elementary Science, National Science Teachers Association, for his guidance through various stages of the project; to Everett Collin, Mattison Storey, and George Gardner, Specialists, National Aeronautics and Space Administration Education Program, for their interest in the project and for their reading of the manuscripts; and to Lila J. Phillips, Editor for this series, Teachers Publishing Corporation, for her suggestions and aid in the preparation of the final manuscripts for publication.

To the following scientists, who read the manuscripts in their preliminary form for scientific accuracy, the authors and series editor are deeply indebted for their many helpful comments and reactions: Dr. M. G. Seeley, University of Arizona, Tucson, Arizona; Dr. Alexander Calandra, Washington University, St. Louis, Missouri; Dr. Albert R. Hibbs, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California; Dr. Hugh F. Henry, Depauw University, Greencastle, Indiana; Dr. William Mathews III, Lamar State College of Technology, Lamar, Texas; and Dr. Barbara Collins, Geologist, Northridge, California.

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1

INTRODUCTION

SUNGLASSES, LIGHT, AND LEARNING

"I can't understand how you can see me through those mirror sunglasses. *I* can't see *your* eyes," said Chuck.

Tom took off the glasses and looked at them closely. The glass parts appeared to be mirrors on both front and back sides. "I think it's because my eyes are so close to the mirrors that my eyesight can go right through," he said.

"But I thought you could see through only one side. Let me try." Chuck took the glasses and held them with the front sides to his eyes. "Yes! My eyesight can go through this side, too, when I hold them up close."

Mary stepped eagerly from behind the play store counter where she had been waiting on Janet. "Oh, please let me see." Chuck helped Mary put on the glasses, and she agreed that her eyesight also went through the glass when the lenses were close to her eyes.

Janet stood right in front of Mary and said, "Can you really see me?" When Mary nodded, Janet brought her face close to Mary's. "Yes!

Now I see!" she exclaimed. "When I get close enough, my eyesight goes right through and I can see your eyes!"

"That's what I told you," said Tom, taking back the glasses. "Your eyesight will go through any kind of mirror if you hold it close enough to your eyes."

Mrs. Stock had been watching this before-school exchange among her second graders. In fact she had been about to suggest a safe place for Tom's mirror sunglasses when the discussion began. Now, as Tom generalized so broadly on the basis of only one experience, she was mildly alarmed by this clear example of unsound reasoning by Tom and its acceptance by others in the class. Also, she wondered about the phrase "eyesight goes through." It seemed to be an awkward, if not erroneous, way of expressing the nature of transparent objects and the process of seeing.

Mrs. Stock decided to question the group. "Can you really see through all mirrors if your eyes are close enough?" The answers ranged from "Sure! We just looked through these!" to "Yes, unless it has a back on it," to "Maybe it has to be a mirror on both sides." The children agreed that a good way to find out would be to look at some mirrors at home.

During the next few days Mrs. Stock reviewed the section on light in her college science textbook and scanned the elementary science textbooks of the series used at her school. Satisfied that there was a sequence of concepts that her children could understand, she began work in this area. First, she asked Tom and his friends to tell of their experiences with the sunglasses. Then she guided the children to discuss and ask questions about mirrors and light and seeing. Her part in the discussion was to help the children extend their questions in directions she knew would lead to satisfactory answers, not frustrations. She wrote on the chalkboard many of the questions they asked and then guided them to select several that she knew would lead to appropriate investigative activities.

Planning and working with the children led to the development of some of the important rules

for careful thinking in the methods of science:

• Find as much information as possible before trying to answer a puzzling question; read experiment, observe.

• Don't jump to conclusions—first make a guess and then *test it*.

• Be satisfied with an answer only after you have tested it, in several ways when possible.

MOISTURE, HEAT, AND EXPERIMENTING

"—and our plants have grown much larger and greener because the plastic bag holds moist air around them," said Janie. She was finishing her report on the status of the plants enveloped in a large plastic-bag tent.

Miss Condon had helped her fourth graders arrive at the plastic-bag solution to a problem that had developed several weeks before. The children had found some flowering plants in a sunny, sheltered field near school. They agreed to dig up enough for a large flower pot and to keep them blooming in the classroom all winter. However, in the classroom the blossoms soon died and the leaves became hard and brown at the edges, even though there seemed to be plenty of sun and the soil was kept moist. Discussion and search for information from books and from the florist and other adults were encouraged and guided skillfully by Miss Condon. Work on the problem led to the construction of the plastic-bag "greenhouse." Janie's report was part of this continuing project.

After Janie's report, and without any spontaneous critical comment on it by the children, Miss Condon asked, "Do you think that anything besides the moistness of the air has been changed by the plastic bag?"

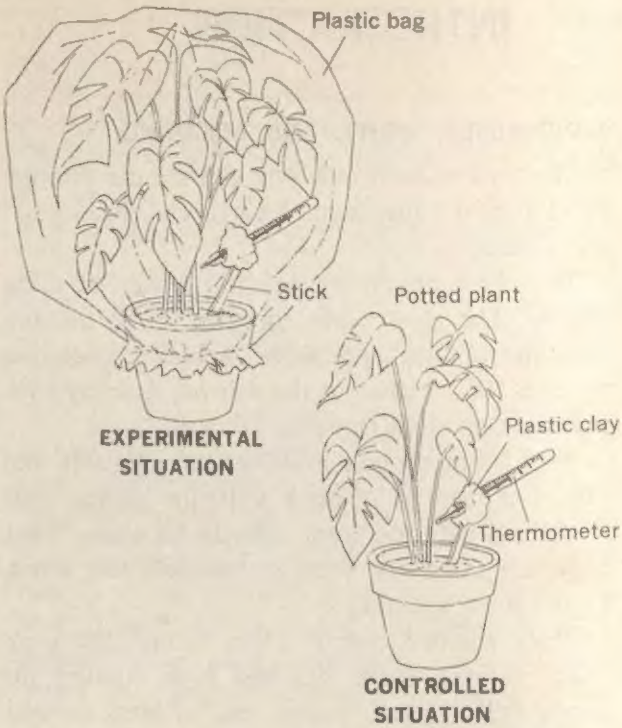
Among the responses were these that she had hoped for:

"It must be cooler inside the bag than it is outside. I see water running down the plastic as it does on an iced tea glass," said Patty.

"Oh no! When I was in the florist's glass hothouse, it was hot and steamy," said Larry.

"But our plants aren't under glass; they're under plastic! Maybe plastic keeps out the heat," said Mike.

After her fourth graders exchanged experiences and opinions, Miss Condon asked if there were not some way they could test their hypotheses. Under Miss Condon's guidance, the children devised an experiment to test their answers. As in most experiments, there was a standard, or controlled, situation as well as the experimental situation. An arrangement such as the one in the illustration allowed the measurement of temperatures in both situations.



It was important to plan ahead with the children to insure that everything was as nearly as possible the same in the two situations, except for the plastic bag on one plant:

• The plants should be given the same amount of water.

• They should receive the same amount of sunlight.

• They should be about the same size. Only when the situations were so set up could the class assume that any consistent difference in the temperatures was caused by the plastic bag and not by some other difference.

A chart to record the temperatures three times each day was constructed. The children spent several days observing, recording, reading, and obtaining further information from parents, farmers, florists, and others.

These two anecdotes have been included in this book because they illustrate an important attitude in teaching science. That is, that science teaching in the elementary school need not be the frightening task one who is not a science

specialist often thinks it is. In fact, as with the children's natural but erroneous observations about the sunglasses, easy and useful openings for starting fruitful science experiences occur often in the course of classroom activities. To clear up the erroneous concepts children have about how and why things work is not the only function of science, of course. The very process of investigating, hypothesizing, and testing is at least as important a part of science as the concepts children develop. Opportunities for initiating science studies arise more naturally and freely, perhaps, than do similar opportunities for starting work on the more abstract subjects of language arts or mathematics, if a teacher is willing to take advantage of them.

The major concepts in this book, which is concerned with energy, are relatively few. The process of developing the concepts for children is one of selecting and presenting many smaller steps or sequences of steps that build up to the desired understanding in a logical way. It is this method of presenting basic, important concepts of energy in small understandable bits of demonstrable information that should help to remove the aura of remoteness of science, and, hence, the difficulty of teaching science, from the teacher's mind.

THE CONSERVATION OF ENERGY PRINCIPLE —WAVE FORMS OF ENERGY

Activities in this book are intended to help teachers develop three major concepts that make up a large part of the "conservation of energy principle." This principle is as follows: that energy in one form may be transformed to other forms of energy, but cannot be created or destroyed under ordinary conditions. Important to the understanding of this principle are the following concepts:

1. Energy may travel in the form of waves.
2. Wave forms of energy may move through materials or through electromagnetic fields.
3. Wave forms of energy may be transformed into other forms of energy or work.

Immediately, a definition and explanation of the theory of wave forms is needed in order to present these concepts clearly.

Wave Forms of Energy: An important concept basic to the understanding of energy is that some types of energy travel or move in the form of waves. These forms of energy exist as a disturbance or series of disturbances that move through a material, such as water. When a stone is dropped into a pond, particles of water are pushed down (disturbed). Those water particles disturb the ones next to them, and so on, with the result that ripples (disturbances) are made. Ripples constitute a path of energy, and this energy often does work of some sort, such as moving the soil at the edge of the pond.

Besides moving through materials in the form of waves, energy also moves through electromagnetic fields in this form. For instance, though electromagnetic fields cannot be seen, when a lightning flash occurs, light, sound, and radio waves are produced. Fast-moving electrically charged particles in the atmosphere cause disturbances (waves) that move rapidly outward through the surrounding electromagnetic fields.

Other terms that will be helpful to remember and always to use precisely are the following:

Energy: The ability to do work; any form of energy may be converted to another form of energy that can do work.

Work: The process of moving an object, against some force, across some distance.

Electromagnetic Fields: Patterns of electric and magnetic forces surrounding and extending outward into space from magnets and objects that have been electrically charged.

Thus, the concept of waves as the form in which energy moves is necessary to our understanding of sound, radio, heat, and light. To scientists and technologists, wave theory is a successful tool in developing new understandings of the sizes and energies of atomic particles; the speeds and distances of stars; and ways to make transistors, color television, and the electronic brains that control so many modern devices. To teachers and students, wave theory should also be helpful in making clear the basic concepts of what energy is and does, and of how the principle of energy conservation operates. In this book, the Activities will show how to investigate phenomena that give evidence in support of wave theory and phenomena that may be explained by this theory. In addition, the Activities will show some of the energy transformations that demonstrate clearly the conservation of energy principle.

2

INVESTIGATING WAVE FORMS

Some types of energy, such as sound waves, heat waves, and light waves, travel as a series of disturbances in the medium in which they exist. This type of energy is said to travel in waves. These waves have characteristic shapes, called wave forms, which to a large extent determine many of their properties.

Children's questions often indicate the scope of interest and experience they bring to an investigation of energy waves:

"Did the big waves at the seashore push you down?"

"Did you feel the ground shake when the train went by?"

"Where do waves come from?"

It might be said that the continued technological progress of our civilization rests upon the fullest utilization of the energy that is available to it. To fully understand energy, it is necessary for us to understand the form of the waves in which it travels.

Among the concepts to be developed by the study of energy waves are some that are fundamental:

(x) Ripples, shocks, quakes, trembling, and vibration are energy waves traveling through materials.

(x,y) Some energy waves begin in a material when the application of energy causes a part of the material to move.

(y) An energy wave in a material may do work on an object with which it comes in contact, for example, moving the sand on a beach, vibrating an eardrum, or shaking a building.

(z) The Conservation of Energy Principle: Energy is neither created nor destroyed but may be transformed or converted from one form to another under ordinary conditions.

Children often ask, "What happened to the energy that was carried by the waves in a rope after the waves died down?" Although it was not readily apparent, the wave's energy was converted to heat energy. The movement of the rope through the air caused a slight heating of both the rope and the air because of friction. However, the heating was spread so far out into the surroundings that the temperature rise in any one place was probably not detectable. A demonstration of this energy conversion would require a well-insulated container to prevent the spread, or "escape," of heat to the surroundings. Such a demonstration is not described because the time and care required may be impractical in your classroom.

These concepts must be fully developed to help children interpret their experiences with the wave forms of energy. Some concepts are specific to the Activities in which they are developed. Others are more general and thus will appear in a number of Activities, supplementing the concepts specific to these.

Generally, the Activities suggested lend themselves to investigation. It is hoped that the children will become involved in them as investigators: will try to find the best answer to a question, will try to demonstrate a relationship, and will test a belief or a tentative answer. The research or investigative approach, at the appropriate level, should emphasize the need for careful and critical thinking, a goal as important as concept development.

WHAT ARE THE CHARACTERISTICS THAT DIFFER IN VARIOUS WAVES?

In these first sections, Activities are described that will help children work with materials in which waves are easily seen. A major purpose of these Activities is to identify the characteristics by which all kinds of waves are described: *frequency* (called pitch in music), *amplitude*, *wavelength*, and *velocity*, or *speed*. The exact meaning and proper use of these words are developed through the Activities. Help the children develop an appreciation for the need to use carefully de-

fined words that provide an objective, quantitative basis for comparisons.

ACTIVITY 1 (x)

OBSERVING WAVES TRAVELING IN A ROPE

Purpose: To demonstrate that waves may be made in a rope and that each wave carries energy

Concept to be developed: Wave forms are the paths along which energy travels.

Materials needed:

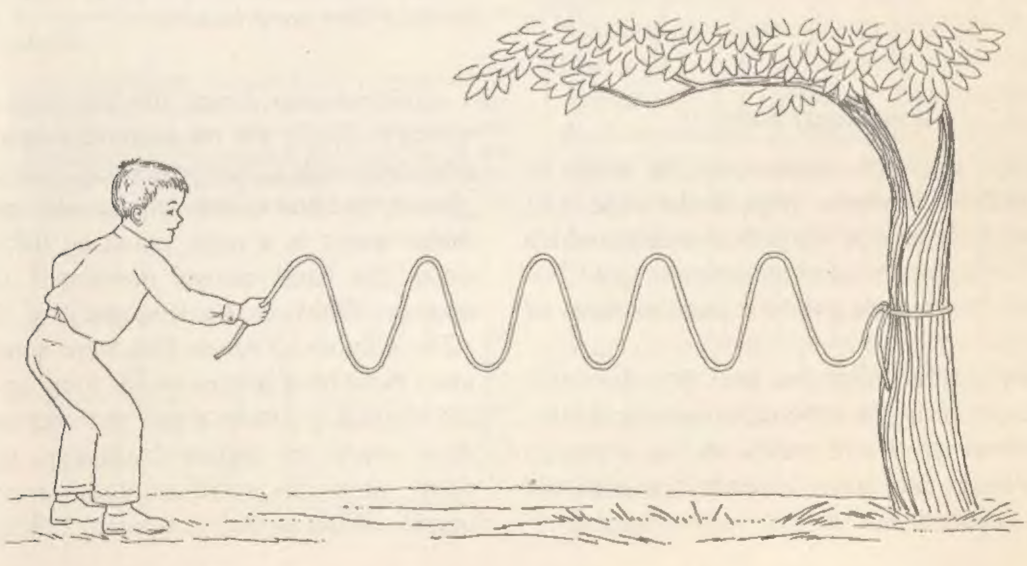
Cotton or nylon clothesline, at least 20 feet (as much as 100 feet may be useful in the following activities)
10 colored pieces of cloth

INTRODUCTION: Have your class describe the waves made in a pond or bathtub as objects are dropped into the water. The children will use descriptive words like big, high, fast, few, many, *etc., but they should be led to see that these words really do not describe the waves adequately or accurately. For instance, a wave may be large in width but not in height; it may move quickly in an up-and-down direction but not in a forward direction; there may be few produced in a period of time, but many altogether, etc. Mention to the children that in science investigations it is necessary to observe, define, and describe accurately what the waves do, and that you will show them how to begin this by using a rope.*

Show a length of clothesline to the class. Ask the children if they can suggest ways to make waves travel along the rope. Have them try their suggestions and see which ones work. Then suggest that one child tie one end of the clothesline to a doorknob or to a tree and pull on the other end so that the rope does not touch the ground. (If the rope is a new one, it is best to stretch it for several minutes before beginning the Activity to remove the kinks and make the rope more pliable.) Then have him try to make large, easily seen waves, by moving the end of the rope up and down rhythmically to make vertical waves, or moving it to the left and right to make horizontal waves. Have another child try striking the rope rhythmically with a stick. Do the children see the waves? *(The best place from which to observe is near one end of the rope.)* Brightly colored pieces of cloth tied on the rope at regular intervals will help to make the motion more apparent to the children.

Mention to them that now that they have seen the waves in the rope, the next question is "How did the waves get there?" Encourage them to advance their theories about this. By this question the concept of applying energy may be introduced.

The concept that rope waves represent the motion of energy has meaning only if the terms *work* and *energy* are carefully defined and used consistently. Work is done when an object is moved, against some opposing force, through a distance; for example, when any object is lifted against the force (pull) of gravity or when any object is allowed to fall against something that resists its downward movement, such as water falling to turn a water wheel. Energy is the potential to do work or to produce another form of energy that can do work. To use these words accurately



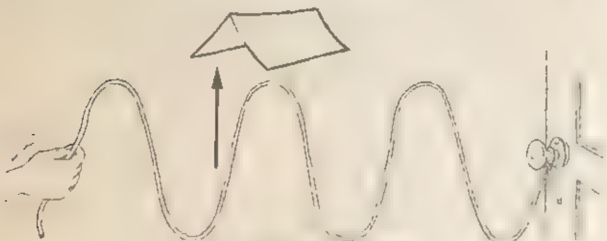
and consistently, of course, is desirable and necessary. Children cannot express their ideas or make comparisons in this area without them.

These leading questions may be key ones in helping your children grasp the concept that energy is carried by the rope waves: Did you do some work to make the waves? *(Yes, in moving the rope against gravity.)* Can you make waves that have more energy? that have less energy? *(Yes, by moving the rope up and down more or less forcefully.)*

The children may test the latter answer by creasing a sheet of paper and laying it on the rope like a saddle. Then when a child makes a wave move along the rope, the paper will hop up. The child may increase the work he does on the rope by moving his hand up and down a greater distance or by increasing the force and speed of his hand's motion in making a wave. The paper saddle will serve as an indication of the amount of energy carried by the rope wave.

Ask the children to suggest other ways to detect the energy in rope waves. For example, try to break a thread that is held next to the moving rope, or to lift a book with the moving rope, or feel the energy by touching the rope. Test the ways the children suggest.

LOW-ENERGY WAVES



HIGH-ENERGY WAVES

Learnings: (x) Rope waves may be made by doing work in moving a part of the rope. (x) The wave in the rope is the path of energy, which may do work in moving other objects. (y,z) Energy may do work or produce another form of energy.

Tell the children that the next Activities will help them to learn more about the various characteristics or properties of waves so that they can learn to make accurate observations and use scientific definitions.

ACTIVITY 2 (x,y,z)

COUNTING FREQUENCIES OF WAVES IN A ROPE

Purpose: To clarify one of the words used to describe waves, **frequency**

Concept to be developed: Frequency is the rate at which waves are produced per unit of time. It is expressed as the number of waves per minute, or when the frequency is high, as the number of waves per second. With some children, you many want to develop the following word formula: "Frequency equals the number of waves divided by the time (the number of seconds or minutes) in which they were made." The formula may be written

$$f \quad n : t, \text{ or } f \quad \frac{n}{t}.$$

(f stands for frequency, n for the number of waves, and t for time.)

Materials needed:

- Cotton or nylon clothesline, 20 feet long, marked at regular intervals with 10 pieces of colored cloth
- Stop watch or watch with a second hand

INTRODUCTION: Ask six children to come to the front of the room and line up in a row. Use a stop watch and ask two of them to touch the floor at five-second intervals, two of them to touch the floor at ten-second intervals, and two of them to touch the floor at fifteen-second intervals. Have each group of two children perform separately, then together, to show the different frequencies. Ask the other children to describe the "frequencies" of touching the floor, in terms of number of acts per period of time. Ask, for example, "How many times does each group touch the floor in a minute? in two minutes?" Then mention that just as they have measured how often (or how frequently) they have touched the floor during one or two minutes, they can also measure the frequency of waves, or the rate at which they are produced.

Children may count the frequencies of rope waves to clarify the meaning of *frequency*. Have one child with a stop watch call time at the beginning and end of one minute and another child make waves in a rope, counting the number of times his hand moves downward during the minute. What is the frequency of the waves? *(The number of waves that were made per minute.)* Now have him move his hand up and down more quickly (more times per minute) to produce waves of higher frequency. Count how many times his hand produces waves in one minute. What is their frequency? Have the child

vary the rate at which he moves his hand to provide practice in expressing frequency as a number of "waves per minute."

Have children check to see whether the frequency of waves arriving at the other end of the rope is the same as the frequency at the "sending" end. Count the frequency at the middle and at other points in a long rope. In these tests, one child calls time, another makes waves and counts them, and another holds his finger at a point on the rope and counts the waves as the rope waves tap his finger. Is the frequency the same at all points along the rope? *(The frequency counted at any point along the rope should be the same as the frequency of "sending" the waves.)* Is the frequency of the waves the same throughout in longer and shorter ropes also? *(Yes.)* Have the children make waves in longer and shorter lengths of the rope to prove this.

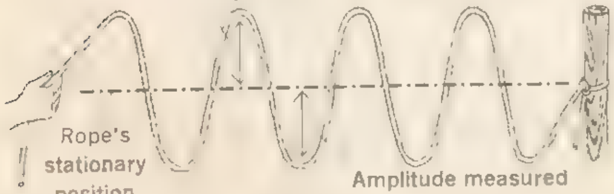
Learnings: (x) Rope waves may be made and may pass a point on the rope at a frequency of a few waves per minute or of many waves per minute. (x,y) Frequency is a characteristic useful in describing and comparing waves; it may be expressed as waves per minute or waves per second. (y) It is incorrect to use *fast* and *slow* as synonyms for *high frequency* and *low frequency*.

ACTIVITY 3 (x,y)

PRODUCING WAVES OF VARIOUS AMPLITUDES IN A ROPE

Purpose: To clarify another of the characteristics of a wave, amplitude

Concept to be developed: Amplitude is a measure of the amount of energy carried by a wave. (In the rope waves made by moving the end of the rope up and down, the amplitude is proportional to the distance the rope moves from its stationary position up to the wave crests or down to the troughs, as shown in the illustration.)



Materials needed:

Cotton clothesline, 20 feet long, marked at regular intervals with 10 pieces of colored cloth
Yardstick

INTRODUCTION: Draw two pictures on the chalkboard showing waves of varying heights. Mention that the smaller waves are like those in a calm sea, and that the taller waves are like those in the same sea during a storm. Have the children decide what it is that has made the difference in the height of the waves, in order to bring out the idea that the force of the wind, or energy, has affected the tallness of the waves. Mention that this varying difference in height, caused by energy, is another characteristic of waves, called amplitude, and that it can be measured. Ask the children, "How can we measure the amplitude (or the amount of energy) of a wave in a rope?"

The following experiences may help children understand *amplitude* as a characteristic useful in describing waves. (It should be noted that for waves made in a rope the amount of slack left in the rope is directly reflected in the amplitude of the waves as they travel. Several trials may be necessary to establish the proper amount of slack that will best demonstrate the concept of this Activity.) Have a child make high-amplitude waves by moving the end of the rope very high and very low as he makes waves in it. Another child may hold a yardstick (vertically), with the 18-inch division at the starting point of the rope, beside the first child's hand to measure the amplitude. What is the amplitude of a wave made by moving the rope up and down, from the top to the bottom of the yardstick? *(The amplitude is 18 inches, measured from the center up to the crest or down to the trough of the wave.)* Have the children measure the amplitudes of smaller waves (12-inch and 6-inch amplitudes are convenient). If the weight of the rope makes it difficult to control in the up-and-down motion, the waves may be made horizontally by moving the hand left and right, in which case the yardstick must be held horizontally.

In order to compare the energy and amplitude relationships of waves, you may help a child learn to make waves of the same frequency, but of high and low amplitudes. As one child makes 6-inch amplitude waves by moving the end of the rope as above, have another child count seconds of time (saying, "One thousand one, one thousand two, one thousand three . . ." as an

approximation). The child making the waves can adjust the frequency to a steady two-waves-per-second rhythm. Then, without changing the frequency rhythm, have him begin to make larger (12- or 18-inch) amplitude waves, by moving his hand farther for each wave. Ask him which requires more work? *(Making the larger amplitude waves.)* How can he tell? *(He must move the rope farther and with more force to make the larger amplitude waves; work is the product of force and distance.)* Which waves do you think have the most energy? *(The larger-amplitude waves have the greater energy because of the greater amount of work needed to make them; the paper saddle in Activity 1 demonstrated this and may be used to show it again.)*

Learnings: (x) Rope waves of high amplitudes may be made by moving the rope large distances up and down or left and right; waves of lower amplitude may be made by smaller movements. (x,y) Amplitude is a characteristic useful in describing and comparing waves; it may be expressed in inches or feet, or in other appropriate units of linear measure. (y) High-amplitude rope waves have high energy. (z) The energy carried by waves comes from the energy the child must use to make the waves. Energy is conserved (it is not destroyed or created, but may be converted from one form to another). (z) From observations of waves in a long rope one can see that waves at a distance from the "sender" are of lower amplitude (and thus lower energy) than those close to him. This is true because some of the energy carried by the rope waves is "lost" when it is converted to heat energy by friction as the rope is moved back and forth in the air (though there is too little heating to detect with ordinary thermometers).

ACTIVITY 4 (x,y,z)

MEASURING THE SPEED OF A WAVE IN A ROPE

Purpose: To show still another characteristic of waves, that is, **velocity**

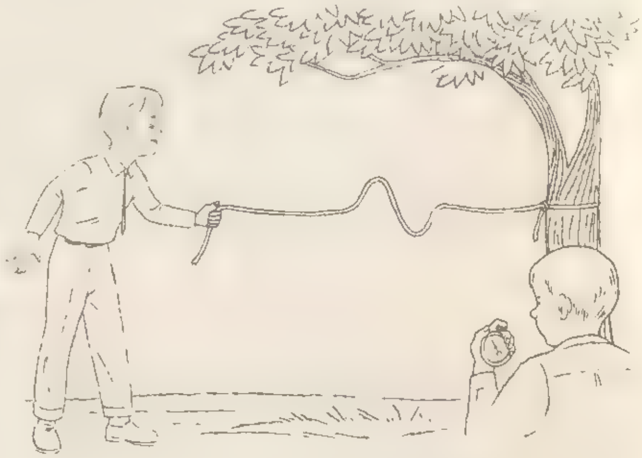
Concept to be developed: The velocity or speed of the waves along a rope is expressed as the distance each wave moves per unit of time.

Materials needed:

Cotton clothesline, 100 feet long, marked at regular intervals with pieces of colored cloth
Stop watch or watch with a second hand

INTRODUCTION: Tell the children that in the next Activity they will actually play the parts of waves to find out another characteristic of waves. Choose two children, perhaps naming them Johnny-wave and Jimmy-wave. Have the two children engage in a foot race over a short distance. Ask the class, "Why did Johnny-wave (or Jimmy-wave) win?" Encourage answers that bring out the fact that the winner ran faster than the loser, and that he covered the distance of the race in a shorter time. Then establish that the speed at which each child covers the same distance in a given length of time is called velocity. Next, ask the class, "Now, let's see if the waves traveling along a rope have velocity. How can we measure it?"

The following experiences will give meaning to the word *velocity*, or *speed*, in relation to waves. Help the children use a stop watch and a very long rope—100 feet works well—to measure the speed of a wave. While the rope is very still, have one child start a single large-amplitude wave. Have another child start the stop watch at the same instant the wave starts and then stop



the watch as the wave reaches the end of the rope. Try this several times, recording the time on each trial. (The Activity should be repeated at least five times to make certain that the times are consistent.) Are the times all the same? *(They will be the same if the rope is held and moved in the same way each time.)* What is the speed of the wave? *(Since speed is the distance traveled each second, the length of the rope must be divided by the number of seconds.)* With some children, you may want to develop the word formula "Velocity equals distance traveled divided by time of travel," which may be written

$$v = d \div t, \text{ or } v = \frac{d}{t}.$$

(v stands for velocity, d for distance, and t for time.) Velocity is often expressed in feet per second.

Sample problem: The rope is 100 feet long, and the times reported by the children are

Trial 1 = 3.0 seconds
Trial 2 = 3.2 seconds
Trial 3 = 3.1 seconds
Trial 4 = 3.2 seconds
Trial 5 = 3.0 seconds

Average = 3.1 seconds

$v = d \div t = 100 \div 3.1 = 32.3$ feet per second.

Other speed units should be discussed with the children, for example:

John Glenn traveled at a speed of nearly 18,000 *miles per hour.*

One glacier moves at the speed of 5 *feet per year.*

The jet plane was going 10 *miles per minute.*

With some groups you may want to develop the number concepts used to convert one speed unit to another. To do this, the following relationships should be established for the children. Put the following information on the board:

1 year = 365 days
1 day = 24 hours
1 hour = 60 minutes
1 minute = 60 seconds
1 mile = 5,280 feet
1 foot = 12 inches

As an example of converting speed units, if a jet plane is traveling at 10 miles per minute, what is its speed in miles per hour?

10 miles per minute × 60 minutes per hour
= 600 miles per hour.

A more complicated example would be to convert the speed of an astronaut's flight (18,000 miles per hour) into feet per second:

$$\frac{18{,}000 \text{ miles per hour} \times 5{,}280 \text{ feet per mile}}{60 \text{ minutes per hour} \times 60 \text{ seconds per minute}}$$

26,400 feet per second.

Learnings: (x) Waves take time to travel through a length of rope; the farther they must travel, the longer the time it will take. (y) Speed, or velocity, is measured in units such as feet per second, miles per hour, etc. (y,z) Velocity may be calculated according to the relationship $v = d \div t$, or $v = \frac{d}{t}$. (z) Speed units are interconvertible.

ACTIVITY 5 (x,y,z)

COMPARING THE SPEED OF WAVES OF HIGH AND LOW FREQUENCIES

Purpose: To show that the amplitude of a wave has no effect upon its velocity

Concept to be developed: The velocity of a wave is independent of its amplitude, and the velocity of waves is constant.

Materials needed:

Cotton clothesline, 100 feet long, marked at regular intervals with pieces of colored cloth
Stop watch or watch with a second hand

INTRODUCTION: Ask the class, "Do high-amplitude waves travel at the same speed as low-amplitude waves in a rope? How can we test this?" Let the children give their ideas and help them decide how many trials they should make to test their ideas. Have them use the long rope and use the stop watch to time very small waves and then very large ones.

Perhaps a child will suggest a "wave race" in two ropes side by side. For this, the long rope could be divided by looping its middle around a post or tree. Have two children stand side by side, holding the two ends of the rope. On a given signal, they each start a wave traveling along the rope. Another child at the post or tree, with a hand touching each rope, can best judge which wave arrives first. Record the results of each trial.

The children should find that the speeds of all waves in the same rope are approximately the same. When they get a result very much in error, discuss the many things that may have happened —usually human failures—and emphasize the need for many trials to establish a usable, consistent average.

These same techniques may be used to test the speed of waves in different kinds of ropes—thick and thin ropes, ropes made of different materials, etc.

Learnings: (y,z) Low- and high-amplitude waves have the same speeds in the same rope. (y,z) Comparing a number of trials helps to eliminate the possibility of using erroneous measurements.

ACTIVITY 6 (x,y)

MEASURING WAVES TO FIND THEIR WAVELENGTH

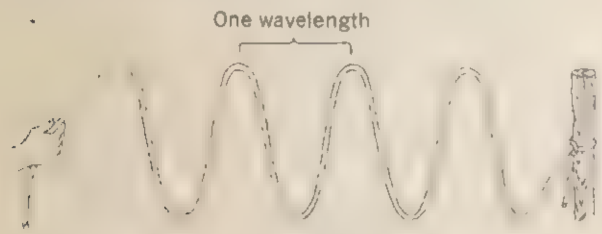
Purpose: To illustrate another of the characteristic properties of waves, **wavelength**

Concept to be developed: Wavelength is the distance between similar points on consecutive crests or troughs of waves.

Materials needed:

Cotton clothesline, 20 feet long
Yardstick

INTRODUCTION: Ask a child to come to the front of the room and draw a picture on the chalkboard of how he thinks an ocean wave would look from the side if it could be stopped in its motion. Ask the child to draw several waves in succession. Pointing to the waves, introduce the idea that the waves have crests and troughs. Explain that a wavelength includes one complete crest and one complete trough. Develop from this the idea that wavelength is measured by considering only one wave, not a series of waves. Ask the children to suggest ways to measure the length. Let them try out their ideas. They will discover that using a yardstick or a tape measure is unsatisfactory because the waves are moving so rapidly that measuring a wavelength directly is difficult, if not impossible.



One method that will produce waves that may be measured with a yardstick is to move the end of the rope rhythmically left and right while the rope is on the floor or on smooth ground. Then suddenly stop moving the rope. Some rather well-defined wave forms should remain in the rope near the "sending" end. You may measure their wavelengths and their amplitudes quite readily now that the rope has stopped moving. It should be made clear to the children that the results of this Activity are comparatively inaccurate, for a part of the energy carried by the rope waves is "lost" (converted to heat energy) in combating the frictional forces between the ground and the rope that oppose the motion of the rope. That this energy is "lost" is apparent from the fact that the amplitude and wavelength of the rope waves decrease noticeably as the distance from the "sending" end increases.

Learning: (x) The wavelength is the distance between similar points on consecutive crests and troughs of a wave.

ACTIVITY 7 (y,z)

PHOTOGRAPHING WAVES TO FIND THEIR WAVELENGTH

Purpose: To provide a more accurate method for measuring wavelength

Concept to be developed: Rapidly moving objects can be "stopped" on a photograph and examined more closely than by direct measurement.

Materials needed:

2 20- to 50-foot lengths of cotton clothesline, one marked at intervals of 1 foot by pieces of colored cloth
Camera (Polaroid or flash-type is desirable)

INTRODUCTION: Hold up a newspaper photograph of a swiftly moving horse, automobile, or airplane. Ask the children to point out distinct features in the photograph. Ask the class, "Is it easier to see these things in the photograph than it would be if the object itself were moving?" Ask, "Why is this so?" Encourage the children to evolve the idea of "stopping" motion in a photograph.

As was seen in the last Activity, it is very difficult to measure wavelengths directly. Therefore, an indirect method must be used. One means of doing this is to use a camera. Have two children stretch out the rope with the colored markers between them. Have two other children, standing alongside the first two, stretch the second rope between them and then make waves in it. A picture taken while the waves are being made will show the rope waves against a scale (the rope with the colored markers) so that the wavelength can easily be determined. (It may be necessary to have the picture enlarged for easy use.)

On a bright day a picture of waves in a rope may be taken with almost any camera. With shutter speeds of 1/100 second or faster there is very little blur. Of course, a Polaroid camera will have the advantage of providing a picture immediately. If the rope is blurred, try painting or chalking it white and/or photographing it in subdued light, using a flash attachment.

Learnings: (x,y) The distance between similar points on consecutive wave crests or troughs is

the wavelength, another characteristic by which waves may be described. (y,z) Fast-moving objects can be "stopped" on a photograph and examined easily.

ACTIVITY 8 (y,z)

CALCULATING WAVELENGTHS FROM FREQUENCY AND SPEED

Purpose: To show that the wavelength and frequency of a wave are related

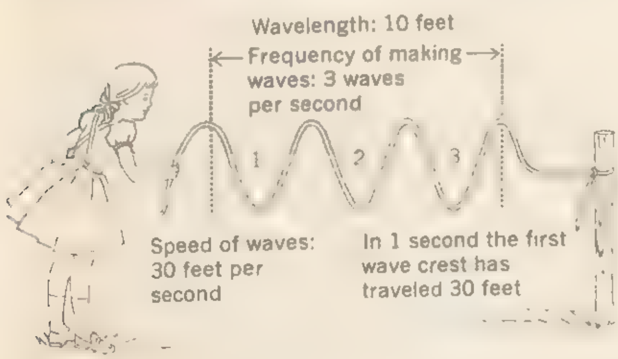
Concept to be developed: If they are traveling at the same speed, waves of high frequency have shorter wavelengths than waves of low frequency.

Materials needed:

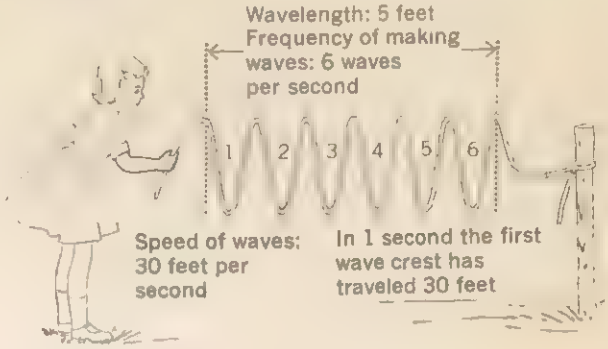
Chalk and chalkboard or pencil and paper

INTRODUCTION: Show the picture of the rope waves made in Activity 7 to the children and ask them, "If the waves in the picture were ocean waves, and if a storm should increase the frequency of the ocean waves, would the distance between the waves be the same as before the storm?" Encourage the children to discuss this question.

Because wavelengths in ropes cannot be measured directly, a calculation based on the frequency and speed of the waves is often used. The basis for this calculation may be shown by two examples: (1) In a rope where the speed of waves is 30 feet per second, a child starts to move the end of the rope to make three waves per second. At the end of one second, the first wave he made has traveled 30 feet and there are three waves between the child and the 30-foot point on the rope. What is the wavelength? Draw the wave



picture on the chalkboard as in the illustration to show that the distance between wave crests (the wavelength) is 10 feet. (2) In this example, assuming that the same rope is being used (so that the waves still travel at 30 feet per second), the child makes waves at the rate of six waves



per second. Therefore, at the end of one second, the first wave he has made has traveled 30 feet and there are six waves between the child and the 30-foot point on the rope. Draw this wave picture on the chalkboard to show that the distance between the wave crests is 5 feet. When the drawings of these two wave trains are compared on the chalkboard, a relationship between frequency and wavelength (assuming a constant velocity) becomes apparent:

- High-frequency waves have short wavelengths.
- Low-frequency waves have long wavelengths.

With some children you may want to develop the word formula "Wavelength equals the velocity divided by the frequency," which may be written

$$l = v \div f, \text{ or } l = \frac{v}{f}.$$

(l stands for wavelength, v for velocity, and f for frequency. The Greek letter *lambda*, λ, is generally used to designate wavelength.)

After the children have determined the speed of wave travel in the rope (as in Activity 4), they may calculate wavelengths of the various frequency waves they can make by simply dividing velocity by frequency (both must be *per second*).

Learnings: (x,y) The wavelength always changes when the frequency of the wave changes. (y,z) High-frequency waves have shorter wavelengths than low-frequency waves if they have the same velocity. (z) Wavelengths may be calculated $l = v \div f$, or $l = \frac{v}{f}$ (caution: v and f must both have the *same* time units).

Summing Up Ideas: Every wave may be described by its four characteristic properties: its frequency, its amplitude, its speed, or velocity, and its wavelength. Frequency is the number of waves produced in a specified period of time, amplitude is the measure of the amount of energy carried by the wave, velocity is the distance one wave travels in a specified period of time, and wavelength is the distance between consecutive similar points on crests or troughs in the wave train. If the distance traveled by a wave in a measured time interval is known, the velocity may be calculated by the equation

$$v = d \div t, \text{ or } v = \frac{d}{t},$$

where v is the velocity, d is the distance, and t is the time interval. If the velocity and frequency of the wave are known, the wavelength may be calculated by the equation

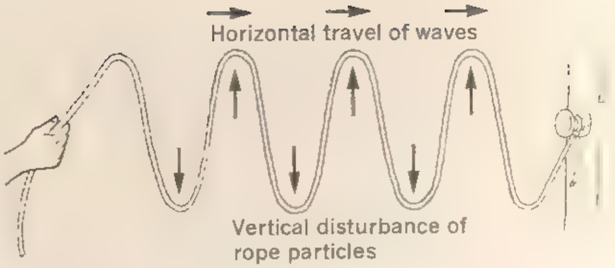
$$l = v \div f, \text{ or } l = \frac{v}{f},$$

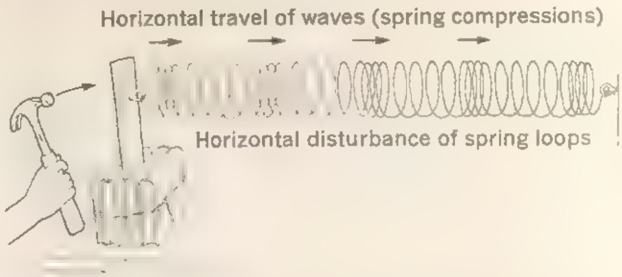
where l is the wavelength, v is the velocity, and f is the frequency.

HOW DO WAVES MOVE THROUGH MATERIALS? Waves may be pictured as energy-caused and energy-carrying disturbances of the particles (atoms or molecules) of which materials are made. A wave disturbance moves through a rope from the "sender" because the particles of the rope moved by the "sender" move the particles next to them and they in turn move the next ones and so the wave travels.

Wave disturbances move through materials such as earth (solids), water (liquids), and air (gases) in two very distinct ways, that is, as two distinct kinds of waves: *transverse waves* and *longitudinal waves*. In this section Activities are described that will help children develop new concepts in this area of knowledge and develop more effective thinking and problem-solving skills.

Transverse waves: The waves made in the ropes were of the transverse type. So are ripples and waves traveling across water surfaces. In making transverse waves, the particles of the material are disturbed in one direction and the waves travel in a direction at right angles (perpendicular) to the direction of disturbance of the particles.





Longitudinal waves: Waves in springs, air, and in other compressible, elastic materials may be longitudinal. In making longitudinal waves, the particles of the material are disturbed in one direction and the waves travel in that *same* direction through the material, a process quite different from the right-angle travel of transverse waves! In the illustration, longitudinal waves are being produced in a long spring by tapping one end of it. Note that the direction of disturbance of the loops and particles of the spring is horizontal and that the waves of spring compression thus move through the spring horizontally.

Compressions of spring loops correspond to wave crests in the rope. The compressional disturbances called longitudinal waves are described in terms of amplitude, speed, frequency, and wavelength—the same terms used to describe transverse waves.

ACTIVITY 9 (x)

COMPARING TRANSVERSE WAVES IN VARIOUS SOLIDS

Purpose: To study the appearance of transverse waves in a variety of solid materials

Concept to be developed: Transverse waves may travel through many different materials.

Materials needed:

Bed sheet or tablecloth
Canvas ribbon, canvas belting, or fire hose
Carpet runner
Chain
Garden hose

INTRODUCTION: Place the bed sheet or tablecloth flat on the floor in front of the children. Ask the children, "Do you think we can make waves in this like the waves we made in the ropes?" Let several children try to make waves in the bed sheet in the following manner.

Place the sheet on the floor. Move one edge up and down rhythmically and watch the ripples move across it. Have children make waves of different frequencies, different wavelengths, and different amplitudes, by applying their previous learnings. Try making waves in the other materials: long carpet runner, garden hose, chain. Establish with the children the meaning of *transverse* by explaining that in such waves particles in the sheet are disturbed in one direction, and the waves travel in a direction at right angles to the direction of disturbance of the particles.

Skill in recording and in thinking logically and critically may be developed by the children as they discuss and plan ways to summarize their findings. Help them make photographs, drawings, sentence charts, or notebooks to record their findings. They may compare the following:

• The amounts of energy used to make the same wave forms in different materials.

• The largest and smallest amplitudes, frequencies, and wavelengths they were able to make in the different materials.

• The speeds of wave travel in the different materials.

Learnings: (x) Transverse waves may be made to go through many materials. (x,y) More energy is needed to form waves in some materials than in others. (y,z) Waves of certain characteristics are easier to form in some materials than in others (that is, waves with high frequency, high amplitude, etc.).

ACTIVITY 10 (x,y,z)

MAKING AND USING A TROUGH TO OBSERVE WATER SURFACE WAVES

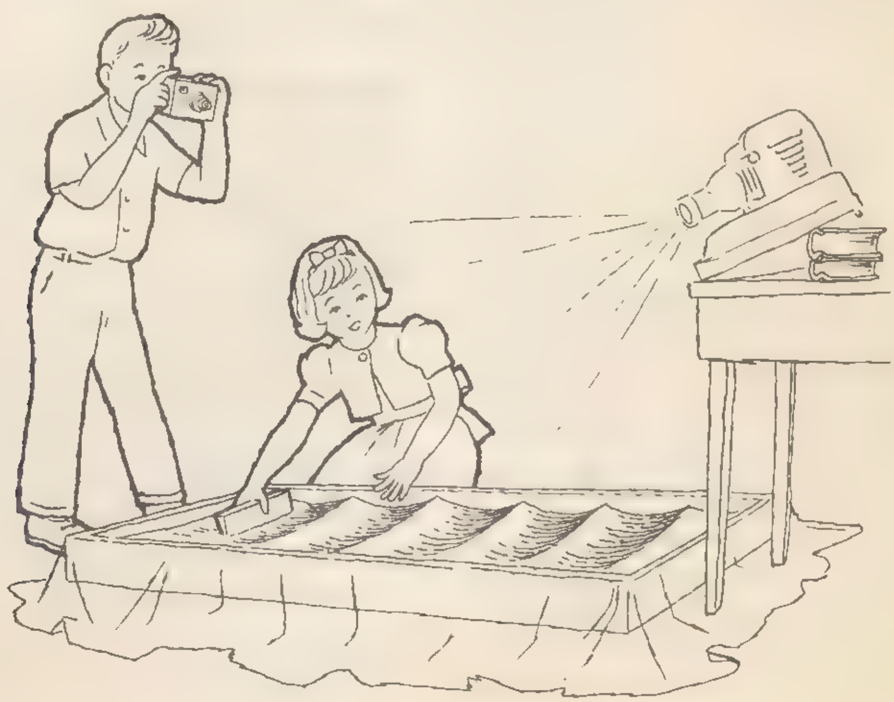
Purpose: To observe transverse waves on the surface of a liquid

Concept to be developed: Ripples on water and on other liquids are transverse waves traveling on the surface of the liquid.

Materials needed:

- Large plastic table cover or painter's plastic drop cloth (with no holes)
- Sand table or boards about 4 inches wide by 1 inch thick to make a frame at least 2 feet wide and 4 feet long (eight 1½-inch nails for holding the corners together)
- Slide projector (300 watt or larger)
- Camera (Polaroid or flash-type is desirable)
- 6-inch-deep bowl or pan
- Marbles

INTRODUCTION: Fill the pan or bowl with water to a depth of about 3 inches, and place it on your



desk. Have the children gather around the desk, and then drop some marbles into the water. Ask the children to describe the ripples that appear. Make the point that just as the particles in ropes were disturbed by energy to make waves, so in water the same principle applies, and that the Activity to follow will demonstrate this.

If a sand table (or box) is not available, help the children make a frame by sawing and nailing together two end boards 2 feet long and two sides 4 feet long. Lay this large frame or the sand table flat on the floor and line it with the sheet of plastic to complete the trough. Use no tacks and just crumple any excess plastic sheet neatly outside the frame. Add water to a depth of two or three inches (this will hold the lining in place). Now cut one more board almost as wide as the trough. Float it across one end of the trough, and use it to make waves as follows:

When the water is very still, have a child tap the wave-maker board and watch the surface wave move to the opposite end of the trough. Place lights or use a light projector so the children can clearly see the waves. Let sunlight shine on the water or direct the projector so that the reflection of the waves can be seen on the ceiling or on a wall. Have the children use the camera to take photographs of the waves and their reflections. You may have to use shutter speeds of 1/100 second or faster to avoid blurring, or you may photograph the waves in subdued light using flash bulbs. You might ask such questions as "How can we make high-amplitude waves?" *(Move the board farther up and down.)* "Do they have more energy than low-amplitude waves?" *(Yes, for it takes more work to form them. Float objects at the opposite end from the wave-maker and compare the effects of high- and low-amplitude waves on them.)* "How can we make high-frequency waves?" *(Move the board up and down more times per minute.)* "Do they have shorter wavelengths than low-frequency waves?" *(Yes.)*

You will probably need to help the children develop effective problem-solving approaches as they discuss and plan ways to use the trough, make the attachments needed, and measure and observe what takes place so they may answer questions such as " Do low- and high-amplitude waves have the same speeds?" *(Yes, but the time of travel is so short in the trough that it can't be measured with a stop watch.)* Perhaps the children could partition the trough in half and try a wave race between high- and low-amplitude waves. "Can two different frequencies of waves move at the same time?" *(Yes, waves seem to move right through each other.)* Try it with small waves. "What happens when waves from one end meet waves from the other end?" *(They pass right through each other.)*

Scientists studying waves call the trough the children made a ripple tank, and they investigate wave forms, reflections, and interference using various liquids, vibrators, and shapes of tanks and wave-makers.*

If there is a pond nearby, take the children to it on a very still day and help them use the pond to test some of the ideas derived from the trough experiences.

Learnings: (x) Waves on water surfaces are made by applying energy to part of the water surface. (y) Water waves are transverse waves—particles move vertically (up and down) and the waves move horizontally (across the surface). (x,y) Water waves of various frequencies, wavelengths, and amplitudes can be made. (xy) High-amplitude waves carry high energy. (y) High-frequency waves have short wavelengths. (x,y) Rope waves and water waves are alike in many ways. (y,z) Energy is conserved—not destroyed or created, but often transformed from one form to another or expended to do work.

ACTIVITY 11 (x)

COMPARING WAVES IN VARIOUS LIQUIDS

Purpose: To compare the characteristics of transverse waves traveling on the surfaces of different liquids

Concept to be developed: The transverse waves produced on the surface of different liquids have varying characteristics.

Materials needed:

- 6 bowls of the same kind (large but shallow)
- BBs or marbles
- ½ pint each of water, concentrated salt water, mineral oil, maple syrup, molasses, oil floating on water

INTRODUCTION: Remind the children that they have dropped marbles into water to see how waves travel. Then ask them if they think identical waves would be produced in all liquids. Ask them how they think their ideas could best be tested.

* You can find photographs of wave characteristics in *Physics*, Physical Science Study Committee (Boston, D.C. Heath and Company, 1960) pp. 260–284.

Pour each of the liquids (other liquids may be substituted) into a bowl. Have the children work on the floor or on a very solid table so the liquids will be very still. Make disturbances on the surfaces of the liquids by dropping a marble or BB in each and observe the waves that are formed.

You may want to stimulate some critical thinking by the children by raising questions such as "Does the energy of the falling BB make similar waves on each liquid surface?" *(No. The wave characteristics, frequency, wavelength, amplitude, and velocity, vary.)* "Do waves travel with equal speeds in each?" *(No.)* "Can a wave of a particular frequency be produced in each liquid surface?" *(Perhaps.)* "With equal ease?" *(No! The thicker liquids do not form high-frequency waves easily.)*

Here again, photographs of each would be most valuable evidence for accepting or rejecting ideas the children propose in discussing the questions. However, careful observation and judgment should yield satisfactory answers or suggestions for ways to make further tests.

Learnings: (x) Dropping an object in various liquids causes surface waves that may have different characteristics. (y,z) Starting waves of certain characteristics requires more energy in some liquids than in others.

ACTIVITY 12 (x)

SEEING THAT SURFACE WAVES DO NOT EXTEND DEEPLY INTO THE WATER

Purpose: To determine the depth to which transverse waves extend when traveling across a liquid surface

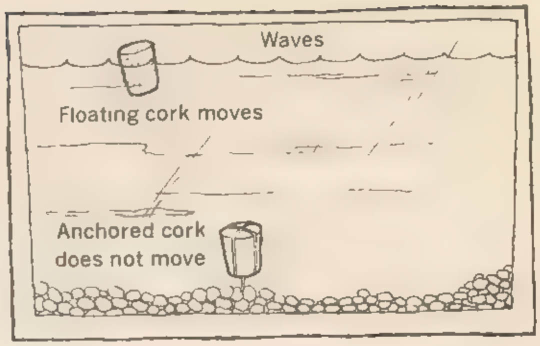
Concept to be developed: Transverse waves travel only on the surface of a liquid.

Materials needed:

Aquarium
Corks
String
Stone or other weight

INTRODUCTION: Fill the aquarium with water and put it on your desk. Put your finger in the water and make a series of waves travel across the surface. Ask the children, "How far down into the water do the waves extend?" Can the children see the waves below the surface of the water? Would a fish feel the waves? Where do the waves go? Tell them that there is a way to find out how deep the waves go.

Have a child tie a cork to a heavy stone anchor with a string and submerge the cork so it is about



2 inches above the bottom of the aquarium. Have him make waves on the surface. What happens to the cork? *(There is no effect on the cork.)* Some children might inquire why the wave does not go deeper than the surface. This is because transverse waves travel only in a direction perpendicular to the direction of the disturbance of the particles.

Learnings: (x,y) Surface waves in liquids do not extend deep in the liquid. (y,z) The energy carried by surface waves travels from particle to particle through the surface.

ACTIVITY 13 (x)

MAKING LONGITUDINAL WAVES IN A SPRING

Purpose: To observe the form of longitudinal waves

Concept to be developed: Longitudinal waves travel through materials in the same direction as the particles of the material they are traveling in were disturbed.

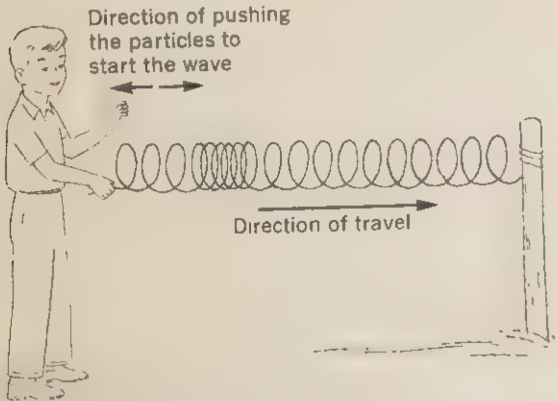
Materials needed:

A "Slinky" spring toy or a spring from the inside of a large window-blind roller
Colored paper tabs
Tape

INTRODUCTION: Point out to the children that longitudinal waves are quite different from the transverse waves that were made in ropes and on liquid surfaces. Longitudinal waves are started by pushing some of the particles of the material in one direction, causing a wave of particles to travel through the material in that same direction. To show this, hold the Slinky in your hands in front of the children. Allow the Slinky to move back and forth from one hand to the other. Ask the children if they think any waves are produced in the Slinky; ask if these waves look like the transverse waves observed in ropes and liquids.

Show the children that longitudinal waves are easily made in the Slinky toy. Stretch it several

feet long, and compress about 6 inches of its loops at one end. Then release them. A wave of compressed loops passes to the other end of the spring and then may bounce back toward the "sender." This wave of compressed loops will be easy for the children to see if they watch from near an end of the Slinky. Tape colored paper tabs to the loops of the Slinky. Children will observe the movement of the tabs when waves pass them.



Learnings: (x) Longitudinal waves, which are quite different from the waves made in ropes and water, may be made in a spring. (y,z) Longitudinal waves travel through a material in the same direction as particles of the material were pushed to start the wave.

ACTIVITY 14 (x)

OBSERVING LONGITUDINAL WAVES AS THEY TRAVEL THROUGH LINES OF DOMINOES AND MARBLES

Purpose: To observe longitudinal waves traveling in materials other than springs

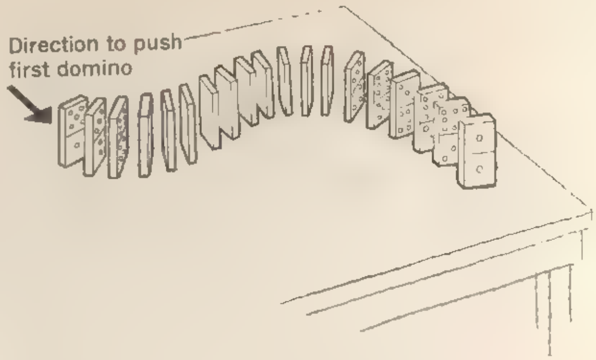
Concept to be developed: A longitudinal wave is a disturbance that travels from particle to particle through a substance in the same direction as the direction of the starting disturbance.

Materials needed:

Set of dominoes
6 or more marbles
Small ball
2 yardsticks
Plastic clay

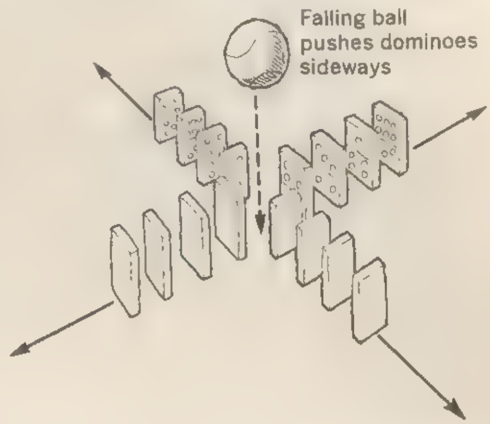
INTRODUCTION: During this Activity place materials such as those listed above on the science table. Use them to demonstrate the process by which disturbances travel longitudinally from particle to particle through a material.

Have the children stand the dominoes on end in a row. What happens if the first domino in the row is pushed? *(The children will discover that when enough energy is applied to tip the first domino in the line of standing dominoes, the disturbance travels from domino to domino until the*



one at the other end is tipped.) A card beside the dominoes may read "Stand the dominoes in a line about 1 inch apart. Push the first domino slowly until it tips over. What happens? Why?"

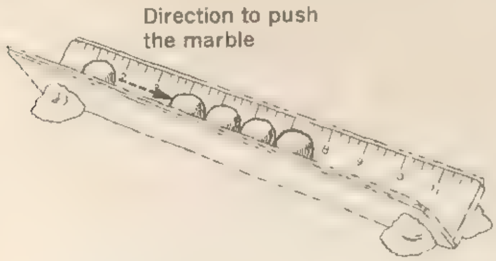
As an alternate Activity the children might arrange the dominoes in the form of an X rather than in a row. They should leave enough space at the center of the X (where the lines of dominoes cross) so that a small ball dropped into the space will topple each of the four dominoes it touches. What happens when the ball is dropped into the center of the X? *(The energy of the ball topples each of the dominoes into the one next to it simultaneously in four directions, that is,*



along each path of the X.) A card placed beside these materials may read "Arrange the dominoes in the form of an X, leaving enough space for the ball to barely fit into the center. Drop the ball into the middle of the X. What happens? Why?"

Have the children make a V-shaped trough with the two yardsticks by placing them together at a 45-degree angle. Insert all but one of the marbles

into the trough so that their edges touch. Then have a child take the one remaining marble and roll it along the bottom of the trough so that it collides with the marbles that have been placed



there. What happens? *(Almost instantly the marble at the other end pops away from the row. This marble will have almost the same amount of energy the first marble had, since the energy—with slight losses due to friction, elasticity, inertia, etc.—has been transferred from marble to marble.)* A card placed beside these materials for the children should read "Place the marbles near the middle of the trough, all touching one another. From one end of the trough, roll a marble toward the others. What happens? Why?"

By the same process, energy may be applied to almost any material in a way to produce a disturbance that moves from particle to particle through the material in the same direction as the original disturbance. It is in this way that a longitudinal wave is produced.

Learnings: (x) A push at one end of a row of dominoes or marbles can travel through the row to the other end. (y,z) A longitudinal wave is a disturbance that travels from particle to particle through a substance in the same direction as the direction of the starting disturbance. (y,z) Energy is present in longitudinal waves in materials. (y,z) Energy can be converted into work, such as moving dominoes and marbles.

ACTIVITY 15 (x)

MAKING LONGITUDINAL WAVES IN A ROPE

Purpose: To show that longitudinal waves can be transmitted by a material that can also transmit transverse waves

Concept to be developed: Longitudinal waves can be transmitted through a material in which we cannot see the particles being disturbed.

Materials needed:

Clothesline, 20 to 50 feet
Broom handle
Hammer

INTRODUCTION: Ask the children, "Do you think that a longitudinal wave will travel through something besides marbles and dominoes? Something in which we cannot see the separate particles, such as a rope? How can we test to find out whether longitudinal waves will pass through a rope?"

Tie one end of a clothesline to a broom handle and have a child pull it taut at the other end. Now, tap the broom handle with a hammer or some similar object and see if the child holding the other end of the line feels the arrival of the longitudinal wave. Try tapping the broom handle rhythmically. Have the child describe what he feels. *(He may feel "pulses" or "shocks" or "jars" or "thumps" as the energy in the wave reaches his hand.)* Discuss the meaning of amplitude and frequency and encourage the children to suggest and test ways to make some longitudinal waves of low amplitude or high amplitude (tap lightly or heavily), high frequency or low frequency (tap rapidly or slowly).

Have the child slacken the rope and make some transverse (up and down) waves for comparison. Discuss the ease of seeing each. (Children can't see longitudinal rope waves easily, but can readily feel them.) Lead the children to ask questions comparing speed, wavelength, amplitude, and frequency of longitudinal and trans-

verse waves. They might ask such questions as "Could we have a wave race between longitudinal and transverse rope waves?" (as in Activity 5). "Can we make both kinds of waves with equal frequencies?" *(Yes. Make equal numbers of waves per minute.)* In the discussions and planning of ways to test and record the answers, excellent opportunities arise to lead children to think carefully and to consider other children's ideas.

Learnings: (x) Longitudinal waves may be made in a rope by tapping a stick tied to one end of it. (x) Longitudinal waves are not easily seen, but may be felt as thuds or pulses. (y,z) Longitudinal waves are described by the same characteristics, frequency, wavelength, amplitude, and velocity, as transverse waves. (y,z) Longitudinal waves transmit energy that comes from the energy applied to the particles of the material in starting the waves. (y,z) Longitudinal waves and transverse waves can travel through the same medium, such as a rope.

Summing Up Ideas: There are two kinds of waves, transverse waves and longitudinal waves. Transverse waves travel in a direction that is at right angles (perpendicular) to the direction of disturbance of the particles. Longitudinal waves travel in the same direction as the direction of the disturbance of the particles. Both longitudinal and transverse waves can travel through solids, liquids, and gases. Both longitudinal and transverse waves can be described by their characteristic properties, that is, frequency, amplitude, wavelength, and velocity.

IMPORTANT IDEAS IN THIS CHAPTER

For the kindergarten, primary, and intermediate grade children, the kinds of ideas with the most meaning and application are the following:

- That waves can be made in many materials besides water, including ropes, air, and wood.
- That waves can be described more accurately by their characteristics than by **big** or **fast.** These characteristics are frequency, amplitude, wavelength, and velocity, or speed.
- That the frequency of a wave is the number of waves produced in a specified time period.
- That the amplitude of a wave is a measure of the amount of energy it is carrying.
- That the wavelength is the distance between consecutive similar points in the wave train.
- That the velocity of a wave is the rate at which the wave travels.
- That there are two different forms of waves, transverse and longitudinal.
- That waves carry energy that can do work.

In the intermediate and upper grades, the children should be led to develop concepts that are more complex and quantitative:

- That transverse waves travel at right angles to the direction *in* which the particles are disturbed.
- That longitudinal waves travel in the same direction in which the particles are disturbed.
- That the velocity and distance traveled by a wave are related and that this relationship may be expressed by the equation

$$v = d \div t, \text{ or } v = \frac{d}{t}$$

(where **v** is the velocity, **d** is the distance, and **t** is the time interval.)

- That the velocity, frequency, and wavelength of a wave are related and that this relationship may be expressed by the equation

$$l = v \div f, \text{ or } l = \frac{v}{f}$$

(where **l** is the wavelength, **v** is the velocity, and **f** is the frequency).

Perhaps even more important than the concepts developed are the many opportunities in the study of waves to develop inquiring minds. It is good to want to know more, and when active minds are put to the task of devising ways to find the answers they need, creativity or resourcefulness should be encouraged. There are many paths to a good answer; some are in the suggested Activities, but some of the best are in modifications your children will suggest! Use them! Seasoned with a little open-minded and critical thinking, these modifications are often successful and are interesting to carry out. Besides, the satisfaction of success resulting from careful, critical thinking leads to more of the same.

3

INVESTIGATING SOUND WAVES

Related to the visible waves we made with the Slinky and the dominoes are invisible waves that travel in air and other materials. Among the more common names for these waves are noise, music, roar, rumble, clatter, sonic boom—all of which are kinds of sounds. Therefore, we call these invisible waves sound waves.

Children's questions often provide leads into the study of sound:

"How does the steamboat (or diesel train) make such a loud low whistle?"

"Why can't you hear voices well under water?"

"Why does the violinist wiggle his fingers as he plays?"

Most of the questions are related to the concept that sound waves are disturbances produced by some kind of energy. These disturbances move from particle to particle as longitudinal waves. Like all other waves, these sound waves have characteristic frequencies, wavelengths, amplitudes, and velocities.

HOW DO SOUND WAVES ORIGINATE AND TRAVEL?

Although sound waves can be propagated in any material, it is best to consider them in relation to air, for it is in this medium that children are most familiar with sound. However, it should be made clear to the children that the same principles that apply to the origination and motion of sound waves in the air hold true for the propagation of sound waves in any other material. The following Activities will make clear the relationship of sound waves to the visible waves the children have studied.

ACTIVITY 16 (x)

SEEING AND FEELING THE VIBRATIONS THAT MAKE SOUND WAVES

Purpose: To show that sound waves are produced by vibrating bodies

Concept to be developed: Sound waves are produced when a vibrating surface causes alternate compressions and expansions of the particles of the air to create a longitudinal wave.

Materials needed:

- Stringed instrument (such as a guitar or a violin)
- Rubber bands
- Metal ruler (thin and springy)
- Puffed cereal grains
- Bell
- Drum

INTRODUCTION: Ring the bell sharply to attract the children's attention. Ring it a second time and quickly put your finger on the bell to stop the ringing. Ask the children, "What was the bell doing while it was ringing? Why did it stop ringing when I placed my finger on it?" Encourage the children to offer their answers and try to explain them. Then suggest that they might try to discover what happened by means of the following Activity.

Using each of the materials listed, have the children suggest and try out ways to make sounds:

Stretch and pluck the rubber bands.

Hold the ruler on a desk, with 6 inches extending over the edge, and twang it.

Pluck the strings of the musical instrument.

Place the drum flat on a desk and scatter the puffed cereal grains across the top; strike the drum and watch the cereal grains "dance."

In each of these experiences, and in others the children may suggest, help the children identify the source of the sound. Develop the meaning of *vibrate* and use it as a synonym for *shake rapidly*, *tremble*, *shiver*, or *oscillate*.

Mention that each of the materials actually did move or vibrate and that this motion caused the particles of air to move and push against one another, thus creating a sound wave. Suggest that the children can feel the vibration by touching the source of the sound with their finger, nose, or ear. Since they can feel the vibration or movement, they will know that energy is present. It is this energy that is transmitted to the air particles and carried as sound waves.

You may wish to make a two-column chart about the sound-makers, such as the one shown in the illustration. In the discussions during the making of the sounds and the preparation of the chart, help the children to develop some of the important listening, speaking, and thinking skills: "Listen carefully and consider the ideas of others." "Say what you mean clearly." "Explain why you think your idea is good."

Learnings: (x) Sound waves are generated by vibrating bodies. (x,y) Sound waves are longitudinal waves, for the vibrating body causes the air particles to move against one another in the same direction as the direction of disturbance.

ACTIVITY 17 (y)

MAKING AND DETECTING WAVES IN THE AIR

Purpose: To show that sound waves are carried by the disturbance of air particles

Concept to be developed: Sound waves are longitudinal waves.

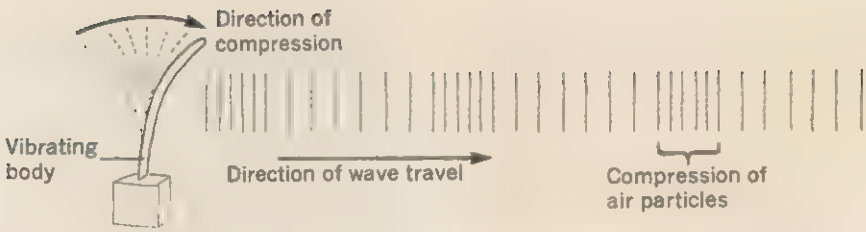
Materials needed:

- Flexible cardboard box (about 12 inches by 10 inches by 2 inches)
- Tape (cellophane, adhesive, or masking)
- Tuning fork
- Soda straw
- Candle

INTRODUCTION: Mention to the children that in the last Activity they discovered that sound waves are caused by vibration and that this vibration causes the air particles to move against one another. But then ask, "How can we prove that sound waves travel through the air as a disturbance of air particles?" Encourage the children to suggest methods of experimentation and then to watch what you will do next.

Place a lighted candle on a desk and, standing 2 to 3 feet away, blow at the flame gently through a soda straw. Observe the difference when blowing in a steady stream (the flame bends away from you and remains that way) and when blowing in short puffs (the flame bends away from you, then weaves back toward its original position, then away from you, etc.). This will be a control Activity for what follows.

Have a child construct an air-wave-maker by cutting a neat, round hole 1 inch in diameter in the center of the bottom of the box. Tape the lid in place and stand the box on its side at one end of a long table. Place a lighted candle 2 to 3 feet away, exactly in front of the hole of the air-wave-maker. The air in the room must be very still. Now, have the child tap the back of the box. Compare what happens to the candle flame to what happened when you blew at the flame through the soda straw. *(The resulting compression of air particles moves as a wave and is directed by the hole toward the flame, which flickers when the compression wave arrives, just as blowing through the straw in short puffs caused it to flicker.)* Try tapping the box rhythmically. Try touching a vibrating tuning fork to the back of the box. Does the candle flame behave in the same manner? *(The flame should flicker each time the box is tapped; it vibrates and looks fuzzy when the vibrating tuning fork touches the box.)* Bring out that the waves are compressional, or longitudinal, because they travel in air just as they did in the rope and other materials. The children may discover that the candle flame is very sensitive to waves of high and low amplitudes—have them compare the candle flame's movement when the box is struck lightly and then forcibly. Why does the flame move more when the box is struck more forcibly? *(The larger amount of energy used in striking the box is converted to waves of higher amplitude, or energy, which in turn do more work in moving the candle flame—the conservation of energy principle.)* How can sound waves be pictured? *(Any object that can be made to move quickly in the air will bat or squeeze or push air particles together.*



This compression of air travels in the same direction as the compressing motion and therefore is truly a longitudinal wave as represented in the illustration. Vibrating bodies produce successive waves in air that travel outward, usually in all directions, not only to the right! This is how sound waves originate and travel.)

Questions children may ask include "Do all vibrating objects make waves in the air?" *(Yes.)* "Can we hear all kinds of air waves?" *(No. Air waves have the frequency of the vibrating body producing them, but only the frequencies of 20 to 20,000 cycles per second can be heard by most people. Some frequencies above 20,000 cycles per second may be heard by dogs, bats, and other animals, but not by people. Dogs respond to "silent" high frequency whistles; bats avoid obstacles at night, by using the echoes of very high frequency sounds they make while flying.)*

You might have the children do library research to see if sonic booms are really sound waves. They result from the compression of air against the leading edges of airplane parts at very high speeds. Does this seem to fit the definition of a sound wave? Could such a wave have high energy?

Learnings: (x) Waves carrying energy can be made to travel through the air. (y) Sound waves are compressions of air particles that travel as longitudinal waves. (y,z) In making sound waves, energy is conserved, neither created nor destroyed, but instead transformed from one form to another.

ACTIVITY 18 (y)

LEARNING ABOUT TUNING FORKS

Purpose: To show that sound waves have differing frequencies

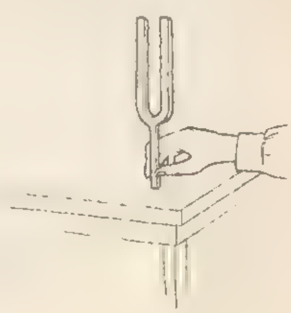
Concept to be developed: Sound waves of a wide range of frequencies can be produced, and these frequencies can be recognized as distinct from one another.

Materials needed:

- 2 tuning forks (one 256C and one 512C)
- Water in a bowl or glass
- Puffed cereal grains
- Rubber striker
- Thread
- Piano or other tuned instrument

INTRODUCTION: Tell the children that you have a problem for them. Then play a simple melody on a piano or other tuned instrument. Point out to the children that the piano produced sound waves that reached their ears, but that not all of the sounds they heard were the same—some sounded higher or louder than others. Point out that since they have heard the different pitches, there must be another characteristic of sound waves they can discover by experimenting. Ask the children, "How can we explain the differences that we hear in sound waves?" Review the general characteristics of waves (frequency, wavelength, and amplitude) and ask if any of them apply to sound waves.

Show the children a tuning fork and demonstrate the proper way to strike it with a rubber striker or against a rubber heel. (Do not strike it against a harder material, for you might chip the tuning fork or produce extraneous sounds that might confuse the children.) Explain to them that a tuning fork marked 256C vibrates 256 times per second when struck, and its vibrations produce longitudinal waves in the air (just as the vibrating bodies in Activity 17 did). The frequency of these waves is 256 cycles (waves) per second, and they are heard as the sound corresponding to the middle-*c* note in music. Have a child strike the 256C tuning fork and press its handle to a table top to make it sound louder.



(The reason the tuning fork sounds louder when pressed against the table top is that it makes the table top vibrate at the same frequency as the tuning fork; thus the vibrating table top reinforces the sound waves produced by the tuning fork, increasing their amplitude.) Find the matching c note on the piano or other available musical instrument. Sound a 512C tuning fork. How does its sound compare with that of the 256C tuning fork? *(A 512C tuning fork vibrates twice as fast as a 256C tuning fork and therefore produces waves of twice the frequency; the greater the frequency of a sound wave, the higher it will sound in the musical scale. Thus, the sound of a 256C tuning fork corresponds to the sound of the c note one octave above the 256C sound.)*

Children may ask, "Why can't we see the tuning fork vibrate?" *(It is difficult to see the tuning fork vibrate after it is struck and impossible to count its rate of vibration because the vibration is so rapid.)* To show that it is vibrating with considerable energy, have a child touch the vibrating tuning fork to his nose or ear. Ask him, "How does it feel?" *(It tickles! buzzes! feels like a shock!)* Or invert the vibrating tuning fork and touch it to the surface of the water in a small bowl or glass. Is there evidence that it is vibrating with some energy? *(It splashes the water far out of the bowl.)*

How could you give the tuning fork more energy? *(By striking it harder.)* Try this.

Tie or glue a grain of puffed cereal to a thread or string and suspend it so it is hanging freely. Bring the vibrating tuning fork toward the cereal grain until it touches. How can you tell that it is vibrating with considerable energy? *(The vibrating tuning fork bats the cereal grain away each time it touches the grain.)*

Learnings: (x) Tuning forks make sound waves by vibrating very rapidly. (x,y) Even though these vibrations are too small or too rapid to see, they have considerable energy. (x,y) The presence of energy in a vibrating tuning fork can be shown by the work it does in moving water or cereal grains.

ACTIVITY 19 (x)

IDENTIFYING SOUNDS BY THEIR CHARACTERISTICS

Purpose: To show that many objects can be identified by the sounds they make

Concept to be developed: Sound waves of characteristic frequencies, wavelengths, and amplitudes are produced by many objects.

Materials needed:

- Objects that make sounds of very short duration: marbles, pencils, drums, etc.
- Objects that continue to make sounds even after the application of energy is stopped: a guitar, bells, chimes, etc.
- Objects that make sounds only as long as energy is being applied: horns, whistles, a harmonica, a stick (to file), a sheet of paper (to tear), etc.

INTRODUCTION: Have the children turn their backs to you while you ring a bell. Ask the children to identify the object that made the sound. Ask the children, "Do you have to see an object that makes a sound in order to know what it is?" This Activity will show that sounds are very different from each other and that by careful listening, we can guess what type of object made a particular sound.

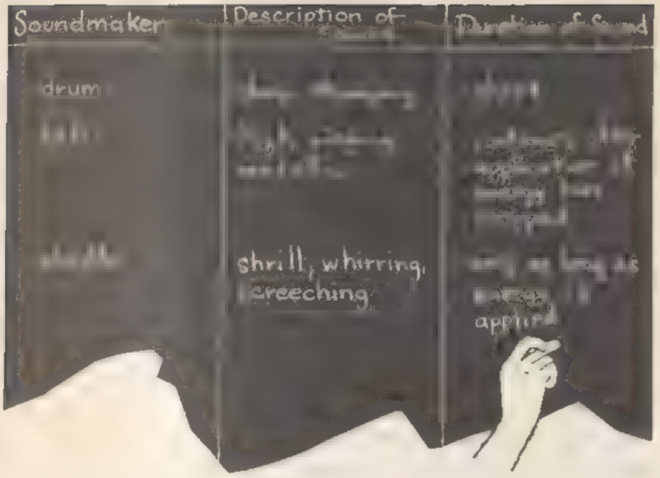
Have the children hide their eyes, blindfold one child, or have the sound-makers hidden behind a screen. Then make the sounds with each of the objects in turn. Have a child identify the object, if he can, and describe its sound. Some of the words useful in describing sounds are these:

ringing	deep	scratching	shrill
clicking	high	rasping	screeching
ripping	resonant	whirring	metallic
tapping	rumbling	humming	thumping
rattling	hissing	bubbling	roaring

An extension of the test would be to distinguish sounds of large and small objects of the same kind.

When you have finished, show the sound-makers you have used to the class. The children might like to organize and classify these sound-makers. Perhaps the children could display some of the objects on a bulletin board or table with cards. On each card a child would write words or sentences describing the kind of sounds made by the object. The display could be arranged in the categories suggested in the material list at the beginning of this Activity. Another kind of organization could be developed on a chart of three columns as on the following page.

With an advanced group you may go on to discuss the question "Why do the objects make different types of sounds?" *(One of the reasons for the difference is that the materials of which the objects are made have different amounts of elasticity, a property that determines the amount of energy of striking or plucking that can be con-*



verted into sustained vibrational motion. Another, more obvious reason for differences in sounds is the shape and size of the object and the forces acting upon the object, all of which determine the frequencies and amplitudes of vibration possible. Small thick objects tend to vibrate at low frequencies; long thick objects tend to vibrate at high frequencies. For example, compare the strings of high and low pitch on a guitar.) Allow the children to study and compare various soundmakers and to discuss the ways they differ or are alike. Encourage them to try to draw conclusions about why objects produce different sounds from the evidence they compile in this way.

Learnings: (x) Sounds are distinctive; certain kinds and sizes and shapes of materials vibrate in ways that make sounds we can recognize. (y,z) Energy must be applied to make the vibrations that produce sound waves. Much of the characteristic sound of an object depends on how much of the energy of striking or plucking is used in making the object vibrate and how rapidly this portion of the energy is converted to heat and other kinds of energy.

Summing Up Ideas: Sound waves are produced by vibrating bodies. A vibrating surface causes alternating compressions and expansions of air particles to create a longitudinal wave. Sound waves of a wide range of frequencies may be produced, and these may be recognized as distinct from one another; certain kinds, sizes, and shapes of materials vibrate in ways that make sounds we can recognize. Like all waves, sound waves have four specific characteristics: frequency, wavelength, amplitude, and velocity.

HOW FAST DO SOUND WAVES TRAVEL?

Since it travels in the form of a wave, sound must have a definite speed, or velocity, for velocity is one of the characteristic properties of all waves. The longitudinal sound waves travel slowly in comparison to the velocity of other wave forms of energy, such as light and heat. However, the speed of sound waves is so great that over short distances they appear to travel almost instantaneously. For example, in a space as small as a classroom there is no significant difference between the instant of arrival of the teacher's voice at a child in the first row and a child in the last row. However, the relatively low speed of the sound waves becomes more apparent when a high-flying airplane is observed. The sound of the airplane's engines always seems to originate from somewhere behind the airplane, for in the time that it takes the sound waves to reach you on the ground, the airplane has moved a considerable distance beyond the point of the sound's origination. In the following Activities the children will gain an understanding of the fact that sound waves travel at a definite, measurable speed.

ACTIVITY 20 (x)

HEARING THAT SOUND WAVES TAKE TIME TO TRAVEL

Purpose: To show that sound waves take a definite interval of time to travel between two points

Concept to be developed: Sound waves have a definite velocity.

Materials needed:

Garden hose (at least 50 feet long)
2 pencils
Hammer

INTRODUCTION: Mention to the children that like other kinds of waves, sound waves have velocity. Review the meaning of velocity as they learned it in Chapter 2. Present the idea of first seeing the lightning and afterward hearing the sound of thunder during an electric storm. Pose the question "Why did we not hear the sound at the same time as we saw the light?" When the children answer that the sound had to travel over a great distance, reply that you have an Activity that will prove that indeed sound does take time to travel.

Spread a garden hose on the floor around the room with the two ends near each other. (Be sure that the hose has no water inside and no holes in it.) Have a child put one end of the hose

to his ear and hold a pencil against the other end. Have a second child tap the pencil with a second pencil while the first child listens carefully. He will hear two clicks—one as he taps the pencil and the other slightly later from the hose at his ear. Bring out that the second click is not an echo but is due to the difference in the time required for sound to travel the long distance through the hose. Discuss this idea and help the children recall other experiences with sound that arrived later. For example, at the ball park or carnival the sound of voices arrives from distant loud-speakers slightly later than from those nearby. Sound does take time to travel!

Learning: (x) Sound waves take time to travel across a distance.

ACTIVITY 21 (x)

OBSERVING THAT SOUND WAVES TRAVEL RELATIVELY SLOWLY

Purpose: To show that sound waves travel more slowly than do light waves

Concept to be developed: Sound waves travel more slowly than do other wave forms of energy, such as light.

Materials needed:

2 flat boards (optional)

INTRODUCTION: Ask the children to think back to the situation mentioned in Activity 20, to how a streak of lightning is seen before the clap of thunder is heard. Ask them to explain what this shows about the speed of sound and light waves. Encourage the children to suggest answers. Then present the following Activity.

This Activity requires the use of a large open space, such as a playground, for the sound waves must be able to travel across a long, unobstructed distance. Have one child walk at least 200 feet away from the rest of the class. When the child is in position, have him clap his hands or two flat boards together as rapidly as he can, six or eight times in succession. The class will notice that the sounds seem to occur while his hands or the boards are apart. If the child claps his hands or the boards rapidly enough, one more clap can be heard after he stops. Sound does take time to travel! Ask the children, "Why did we see his hands (or the boards) come together before we heard the sound of the clap?" *(The light waves, the sight of the hands or the boards being clapped together, traveled faster than the sound waves, the noise of the clapping.)* "Which travel faster, light waves or sound waves?" *(Light waves.)*

Learnings: (x) Sound waves require an interval of time to travel between two points. (x,y) Light waves travel more rapidly (have a greater velocity) than sound waves.

ACTIVITY 22 (z)

MAKING AND CALIBRATING A TIMING DISK

Purpose: To construct a device with which to measure the velocity of sound waves

Concept to be developed: By using the proper tools in a scientific manner, we can make measurements that are difficult to obtain.

Materials needed:

White cardboard (about 13½ inches square)
Phonograph turntable (78 revolutions per minute)
Household or pliobond cement
Pencil lead (thick and soft)
Ball-point pen
String
Tuning fork

INTRODUCTION: In the previous Activities we have developed the concept that sound waves travel at a measurable velocity. Although they travel relatively slowly, sound waves still travel much too rapidly to measure their velocity with a stop watch over the short distances we must work with them. However, by constructing a timing disk, we can provide a means of measuring the short interval of time it takes sound waves to travel across a convenient distance. Making a timing disk may be appropriate and challenging for a group of very able children, for it will demand careful thinking and careful work.

Have the children draw two circles around the center of the white cardboard, one of 6½-inch radius and the other of 6⅛-inch radius. They can use a ball-point pen with one end of a string tied to the pen near its point. The other end of the string must be adjusted to the length desired and held down firmly at the center while the pen is moved around it to draw the circles.

Cut out the 13-inch-diameter circle and punch a hole at its center so the disk fits on the phonograph turntable. Then draw dots ½ inch apart all the way around the 6⅛-inch-radius circle and draw a line from each dot to the center of the disk. The last line drawn is not supposed to fall exactly on the first one, but when the turntable is turning at 78 revolutions per minute,

the lines will pass a stationary marker at the rate of one almost every $\frac{1}{100}$ second.

Some children may be able to work out the mathematical relationships involved:

Since it revolves 78 times per minute, the disk turns more than one revolution in one second. It turns at the rate of $\frac{78}{60}$ (1.3) revolutions per second.

The distance moved by a point on the $6\frac{1}{8}$-inch (or $\frac{49}{8}$-inch) radius circle is obtained from the formula

$$D = 2n\pi r$$

(where D is the distance the point moves, n is the number of revolutions, π is a constant ($\frac{22}{7}$), and r is the radius of the circle). Thus

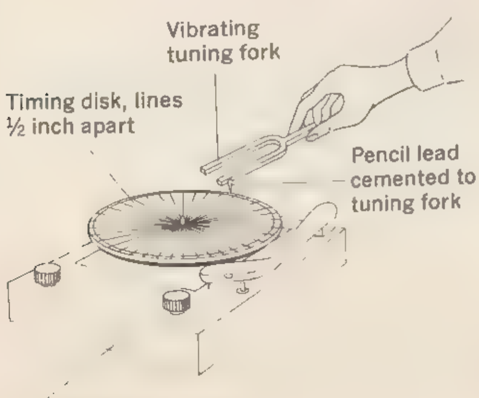
$$D = 2 \times 1 \times \frac{22}{7} \times \frac{49}{8} = 38\frac{1}{2} \text{ inches}$$

for one revolution. Therefore, for $\frac{78}{60}$ revolutions the distance a point moves can be found by

$$D = 2 \times \frac{78}{60} \times \frac{22}{7} \times \frac{49}{8} = 50\frac{1}{20} \text{ inches.}$$

From these calculations it can be seen that a point on the circle moves $100\frac{1}{10}$ half-inch spaces each second. (We may drop the $\frac{1}{10}$, since doing this causes only a very slight inaccuracy.) Therefore, we can say that a line on the disk passes any stationary point every $\frac{1}{100}$ of a second when the turntable is moving at 78 revolutions per second.

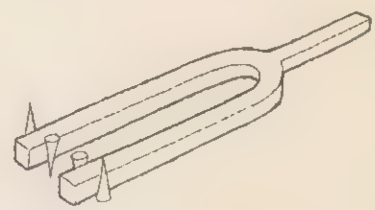
To calibrate the timing disk (that is, to make sure that it is working properly), it may be used to measure a *known* quantity; in this way, by seeing how closely the measurement agrees with the known quantity, the degree of accuracy of the timing disk can be determined. One way of doing this would be to use the timing disk to determine the rate of vibration of a tuning fork (since the true rate of vibration is marked on the tuning fork and can readily be compared to the measured quantity) in the following manner:



Place the disk over a 12-inch record on the turntable. Cement a very soft, sharp piece of pencil lead to one tine of the tuning fork. After starting the turntable, strike the tuning fork and quickly, but gently and steadily, touch the lead to the timing disk as shown in the illustration.

The lead, vibrating with the fork, traces a wiggly line on the fast-moving disk. Have the children practice making good wiggle traces across at least ten lines (ten $\frac{1}{100}$'s of a second) on the disk. On a good tracing count the number of complete wiggles (vibrations) in $\frac{10}{100}$ ($\frac{1}{10}$) second, and multiply by 10 to calculate the number of vibrations in one second.

The results of the Activity may be improved in the following ways:



Cement four pencil leads to the tuning fork. Then, if one pencil lead breaks, tracings of the vibrations will still be made by the remaining leads. Allow the cement to harden overnight to make sure the bond will be strong.

The pencil lead must be soft (1H or 2H are recommended) and very sharp. Rub it on fine sandpaper to sharpen it.

The tuning fork should be of low frequency (256 vibrations per second or lower) so that large, easily countable wiggles will be made on the disk.

The tuning fork must be struck fairly hard and the tracing must be made while it is vibrating with high energy. Be very quick but very gentle. (Previous tracings should be erased before beginning each trial to avoid confusion.)

How closely does the wave count from the tracings agree with the number of vibrations per second marked on the tuning fork? *(The numbers probably will not agree exactly, but they should be fairly close. If not, something is wrong with the timing disk.)* Do the cement and lead affect the tuning fork's rate of vibration? *(They should decrease it slightly.)* Does touching the

tuning fork and the lead against the timing disk affect the turntable's speed? *(The turntable should be slowed slightly.)* Even though these possible errors tend to cancel each other, the children's count for a single observation may be as much as 30 vibrations per second different from the number marked on the tuning fork. However, the results of several tries should be very close to each other.

Scientists often use rotating disks similar to the one constructed to measure rapid speeds and short periods of time. They also must test and compensate for errors inherent in their instruments. One standard test for a disk timer is to check the speed of revolution. The children should count the number of revolutions the turntable makes in one minute. A difference of more than three revolutions per minute will introduce an error that is too large.

Learnings: (y,z) Events that take place over a short time period may be measured on a fast-moving disk. (z) Careful thinking and practice are needed to prepare to measure rapidly occurring events. (z) Some errors in very precise measuring may be anticipated and corrections or allowances must be made for these. Scientists are satisfied with a measurement when its error does not affect the accuracy to any important degree.

ACTIVITY 23 (z)

MEASURING THE SPEED OF SOUND WAVES

Purpose: To measure the speed of sound waves in air

Concept to be developed: The velocity of sound waves in air at sea level is about 1,100 feet per second.

Materials needed:

- Phonograph turntable and timing disk (from Activity 22)
- 2 flat boards (about 18 inches by 6 inches by 1 inch)
- 1 cup of flour or other white powder
- Soda straw
- Pencil lead
- Plastic clay

INTRODUCTION: In the previous Activity we constructed a timing disk. Now we can use it to measure the speed of sound. In using the disk, be sure to have the group performing the Activity show and describe the results they obtain. Help children develop skills in thinking critically and carefully, not jumping to conclusions, in considering other ideas, making careful comparisons, citing evidence for statements made, and stating ideas and questions clearly.

A long open space is needed for this Activity to be successful. The sound waves must have a long enough distance to travel across for the time interval of their crossing to be large enough to measure. If the open space is outside the classroom, the phonograph and timing disk can be placed beside an open window or a long extension cord can be used so that the turntable may be carried outdoors.

To make the moment the sound wave is originated easy to determine, a child can spread flour over one of the boards and then clap the other board solidly against it. The result will be a loud sound and a large puff of "smoke," which can be seen clearly for some distance. The child with the noise-maker must be placed at a carefully measured distance (300 to 800 feet) from where the timing device is located. The timing equipment should be set up as shown in the illustration.

At the instant the child operating the timing device sees the puff of "smoke" at the noise-maker, he must press his finger on the soda straw to bring the pencil lead down on the turning disk. Then, at the instant he hears the distant sound, he must release the soda straw so that the pencil lead will be lifted from the disk. Have a child count the lines on the timing disk that the pencil lead crossed, that is, the number of $\frac{1}{100}$'s of a second it took the sound to travel across the measured distance. Then calculate the velocity of the sound waves by use of the formula for determining velocity or speed:

$$v = d \div t, \text{ or } v = \frac{d}{t}$$

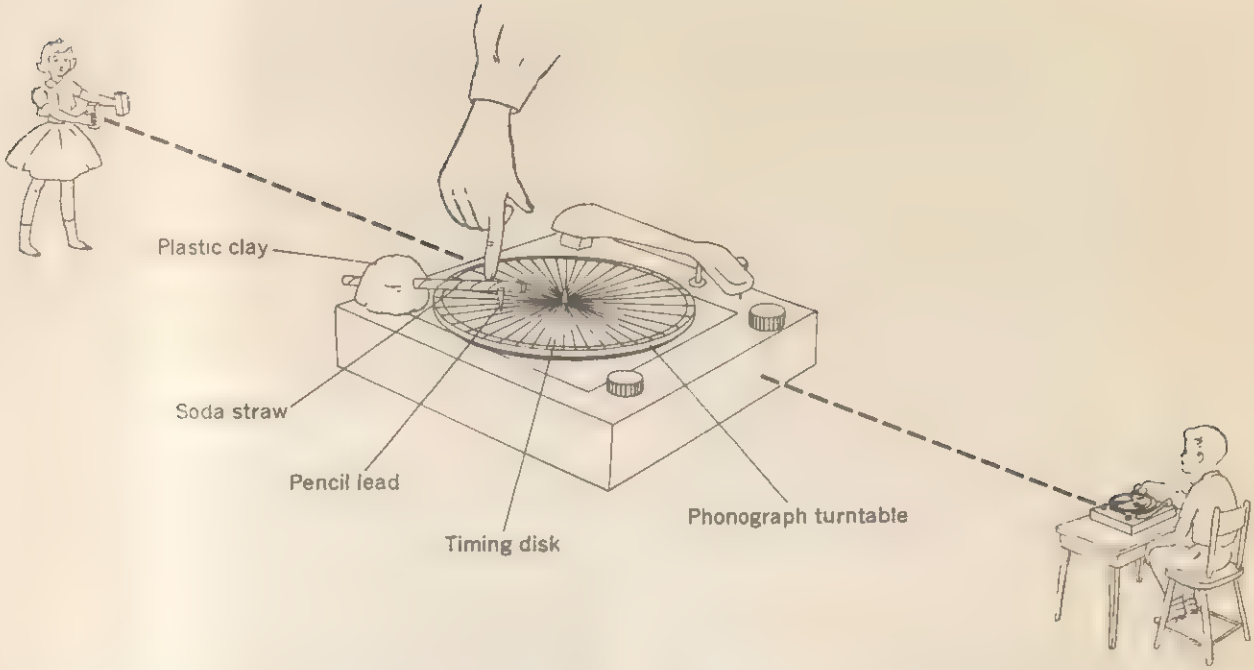
(where v is the velocity or speed, d is the distance, and t is the time interval). Considerable practice will be needed for the child to start and stop marking at the proper instant. Have the children practice many times before attempting an actual measurement.

Example: If the measured distance from the noise-maker to the timing disk is 385 feet and the child marks a line on the timing disk across 35 lines ($\frac{35}{100}$ second), the calculation would be

$$v = d \div t, \text{ or } v = \frac{d}{t},$$

$$v = 385 \div \tfrac{35}{100} = 1{,}100 \text{ feet per second.}$$

It is important to have the children become critical of the accuracy of their work and, even more important, to have them know that precision



is subject to the limitations of tools and people. Discuss the number of trials that must be made. *(At least four or five measurements must be made for the very erratic ones to be discarded. For example, if five measurements are taken and the resulting times are $^{55}/_{100}$, $^{35}/_{100}$, $^{34}/_{100}$, $^{28}/_{100}$, and $^{36}/_{100}$ seconds, the first and fourth measurements are obviously erratic; thus, only the second, third, and fifth trials should be averaged.)* Was the timing disk's (turntable's) speed slowed by the marking pencil? *(Probably a little.)* Did the observer start and stop marking at exactly the proper instants? *(Most people's reaction times are significant and may result in an error in the measurement obtained.)* Would the observer's reaction time in starting and his reaction time in stopping tend to add together and make an error larger than either one? Or would the two reaction times tend to cancel each other and eliminate the error? *(They cancel exactly if they are equal.)*

The speed of sound in air (under usual classroom conditions) is a little more than 1,100 feet per second at sea level. The children's results may be considerably in error on a single trial, but a consistent tendency toward 1,100 feet per second should be obtained if several trials are made. What are the possible reasons for error in a single measurement? *(Discuss the things that may slow the turntable and may distract the observer.)* Lead the children to think carefully and critically and to consider the ideas of others as you discuss their questions and help them test their suggestions to improve their techniques in timing.

Learnings: (y,z) Speed, or velocity, is a measure of distance traveled per unit of time. (z) Error in measuring may be caused by mechanical or human failure, but several trials allow the observer to recognize and discard erratic measurements and to use an average as the correct one.

Summing Up Ideas: Sound travels at a definite and measurable velocity, just as any other wave form does. However, sound waves travel more slowly than other energy waves, such as light waves. At room temperature, sound waves have a velocity of a little over 1,100 feet per second (750 miles per hour) at sea level.

HOW ARE SOUND WAVES AMPLIFIED BY RESONANCE?

Sound waves have an interesting ability. They can cause objects to vibrate at the same frequency they possess. This principle, called *resonance,* finds application in many everyday things. For example, resonance is often used to increase the loudness of musical sounds. The sound boxes of violins, guitars, and ukeleles are shaped to contain air spaces of sizes that amplify various pitches. Such spaces are said to be *resonant* to those pitches. The wood in sound boxes and soundboards may be shaped to make various sections of the wood also resonant to certain

pitches. A guitar soundbox is resonant when a string vibrating with very little energy makes the box vibrate with maximum amplitude. The sound from the box then adds to the sound from the string (reinforces it), making it possible for the sound to be carried over greater distances.

In the following Activities the children will discover what resonance is and how it affects the loudness (amplitude) of sound waves.

ACTIVITY 24 (x)

MAKING THE TUNING FORK SOUND LOUDER

Purpose: To introduce the principle of resonance

Concept to be developed: Resonance increases the amplitude (loudness) of sound waves by reinforcing the waves.

Materials needed:
- Tuning fork
- Rubber striker
- Cello or bass viol (optional)

INTRODUCTION: Strike the tuning fork with the rubber striker and have the children listen while it vibrates. Ask the children, "Is the sound very loud? How can we make the tuning fork sound louder?" Encourage the children to seek their answers through experimentation. Urge them to suggest methods of increasing the amplitude of the sound waves.

Have the class listen to the sound of a vibrating tuning fork. Then touch its handle to a table top. What happens to the sound? Is it louder or softer? *(The sound increases in loudness. Energy from the handle that was being transferred into the soft parts of the hand now moves readily from particle to particle through the solid parts of the table. Air particles touching the table receive this energy and are made to vibrate in the same way. These vibrating particles are added to the vibrating particles being produced by the tuning fork, reinforcing the sound wave—that is, giving it more energy. Explain to the children that this phenomenon is called resonance. The result is that much more of the energy of the vibrating tuning fork reaches the ears of the children, so it sounds louder. This way of increasing the loudness of sound is used in soundboards of pianos, harps, violins, guitars, and other musical instruments.)*

Help the children trace the sound from a vibrating string of a musical instrument to a listener. Is the floor used as a soundboard to make the sound louder when a person plays a cello or bass viol? Help a child test this, using an instrument from the school orchestra. Play the instrument while it is held off the floor and then while it touches the floor.

Learnings: (x) A vibrating body can be made to sound louder if it is brought into contact with another body or surface that can vibrate at the same frequency. (x,y) Sound traveling through the soundboards of musical instruments adds to the amplitude of the sound waves, making the instruments sound louder.

ACTIVITY 25 (y)

MAKING A TUNING FORK VIBRATE BY RESONANCE

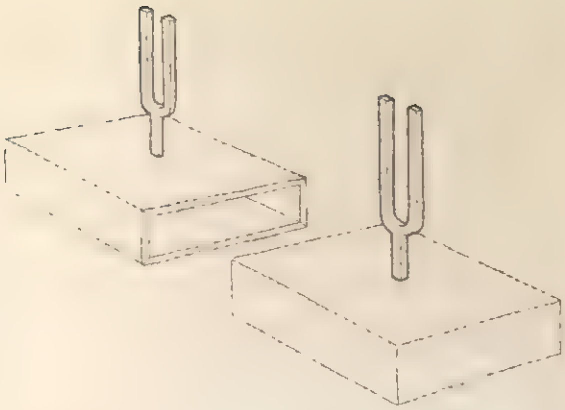
Purpose: To show that a vibrating body can cause another body to vibrate without coming into physical contact with it

Concept to be developed: A vibrating body can cause the particles of a second body to vibrate with the same frequency as the original body.

Materials needed:
- 2 tuning forks of the same frequency (256C)
- 2 identical small wooden boxes, each open only on one side

INTRODUCTION: Ask the children if they have ever heard the story of the singer who could shatter a drinking glass with his voice. Ask them if they have any theories about why this happened. Explain to them that this occurs because of resonance; if a person can sing a note that has a frequency at which a glass can vibrate, the glass will begin to vibrate when he sings that note—we call this sympathetic vibration. If the glass is fragile enough, the vibrations the singer's voice produces in the glass can cause it to shatter. (The singer must be able to maintain a single tone with no variation for a long period of time. Also, the single tone will be a very high one in most cases.) The following Activity will show that a vibrating body can cause a second body to vibrate without touching it, exactly the way a singer can get a glass to vibrate without touching it.

Mount two tuning forks of the same frequency on two identical wooden boxes (one on each box) so that the open sides of the boxes face each other and are about 6 inches apart. Strike either one of the two tuning forks with a rubber striker and let it vibrate for a few moments. Then stop the vibration by putting your hand around the tuning fork you have struck. What do you observe? *(The second tuning fork is now vibrating at the same frequency as the one you had originally struck.)* Why did this happen? *(When the tuning fork you struck began to vibrate, it caused*



the particles of the wooden box it was touching to vibrate; this in turn caused the particles of air within the box to begin vibrating with the same frequency. These vibrating particles of air emerged from the box as sound waves and entered the other box. Inside the second box the vibrating air particles caused the particles of wood to vibrate, and these in turn caused the second tuning fork to begin to vibrate.) Is sympathetic vibration another name for resonance? *(Yes.)*

Learning: (y) A vibrating body can cause a second body to vibrate without touching it.

ACTIVITY 26 (y,z)

FINDING THE RESONANT LENGTH OF A TUBE

Purpose: To show that the amplitude of sound waves can be increased by causing them to reinforce themselves

Concept to be developed: Resonance is an echo phenomenon; the sound waves are amplified when the echoed waves arrive exactly in time to add their energy to that of the waves being produced.

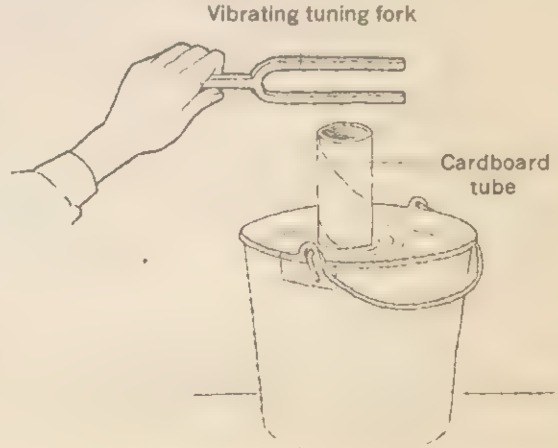
Materials needed:

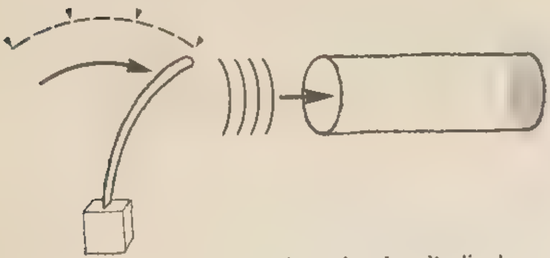
- Tuning forks, 256C and others
- Cardboard tube, 18 inches long and 1½ inches in diameter
- Bucket of water
- Golf ball

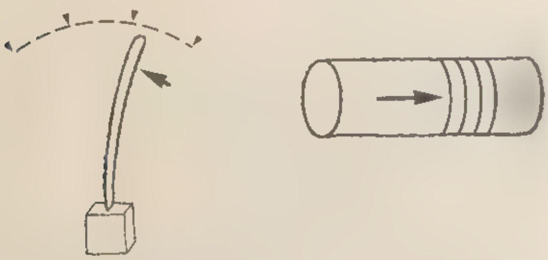
INTRODUCTION: Drop a golf ball down the cardboard tube and let it bounce up and down several times. Ask the children, "If we were to let sound waves travel down the tube, do you think they would bounce back up again the way the golf ball does? Do you think the length of the tube would make any difference?" Encourage the children to plan ways to test the theories they develop.

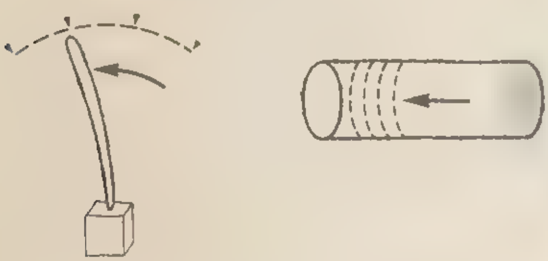
Have a child hold the cardboard tube vertically above the water. Have another child strike a tuning fork marked 256C against a rubber heel and hold it very close to the top of the tube. Let the first child lower the tube into the bucket of water slowly, keeping the tuning fork close to the top of the open tube. Does the sound change? *(It becomes louder when the tube reaches a certain depth.)* Why? *(The reason may be easily seen. In the diagram on page 34, as the vibrating object moves to the right, air is compressed and it travels as a longitudinal wave toward the closed end of the tube, that is, the end in the water. Explain to the children that the wave reflects or echoes from the closed end—in this case, the water—and travels back to the left. Then they will be able to understand that if the tube is one fourth of the wavelength, the wave echo will arrive back at the vibrating object just as it moves to the left. After that, the compression of air to the left moves to the left and is joined by the echoed wave, which reinforces it and makes it sound louder.)* How large is the distance from the open end of the tube to the surface of the water? *(It should be about 13 inches for a 256C tuning fork.)* Since the distance is one fourth the wavelength, what does this tell us about the wavelength of the sound waves emanating from a 256C tuning fork? *(The wavelength is about 52 inches. This can be proved by using the formula for wavelength, $l = v \div f$. Since the velocity of sound in air is about 1,100 feet per second, and the frequency is 256 waves per second, the wavelength is equal to 1,100 divided by 256, which equals 4.3 feet, or 51.6 inches.)*

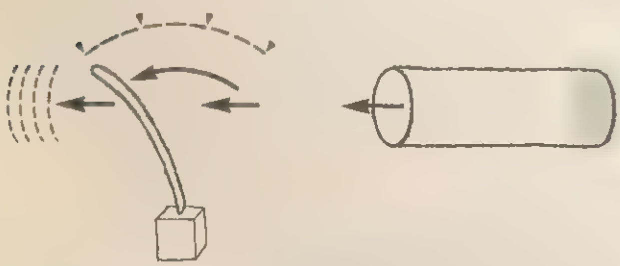
Have the children try the Activity with tuning forks of other wavelengths. What generalization can they make between the frequency of the tuning fork and the length of the tube required to amplify the sound waves? *(The greater the*




Vibrating body moves to the right and sends a longitudinal wave into the tube.


Vibrating body begins to move to the left as the longitudinal wave moves down the tube.


Vibrating body continues to move to the left. Wave "bounces" off the closed end of the tube and now moves to the left.


Vibrating body reaches its left-hand extremity and starts another longitudinal wave, which travels toward the left. Echoed wave arrives at this moment to reinforce the new wave.

frequency of the tuning fork—that is, the higher the pitch—the shorter the length of tube that is needed.)

Learnings: (y) A resonant tube amplifies the sound of a vibrating body. Certain closed-tube lengths are resonant to certain pitch sounds. (y,z) Resonance is an echo phenomenon. The sound is louder when the echoed waves arrive exactly in time to add to the waves being produced (that is, when they are "in phase"). (z) The length of the shortest closed-tube resonant to a sound is one fourth the wavelength of that sound. Wavelength of a sound may be calculated by multiplying four times the length of the shortest resonant tube. This calculation agrees with the one developed in Activity 8,

$$l = v \div f, \text{ or } l = \frac{v}{f}.$$

Summing Up Ideas: Sound waves may cause other bodies to vibrate at the same frequency. We call this type of resonance sympathetic vibration. Resonance causes the amplitude of the sound waves to be increased, that is, to make the waves sound louder. Resonance is an echo phenomenon; that is, the sound waves bounce back to reinforce one another. The length of the shortest closed tube that can act as a resonator (a device that causes resonance) of a particular sound is one fourth the wavelength of that sound.

HOW ARE SOUND WAVES GIVEN DISTINCTIVE PITCHES BY MUSICAL INSTRUMENTS?

Many children ask questions that show they are curious about differences in musical pitch (frequency) and techniques for producing certain pitches. Their experiences have shown them that some musical instruments, such as a piano and a xylophone, can produce a wide range of pitches; that some instruments, such as saxophones and drums, are constructed in different sizes to produce a wider range of pitches; and that some instruments, such as flutes and trumpets, depend upon construction features to produce different pitches. It is relatively easy, therefore, to enrich the children's concepts of the production of sound by musical instruments by enlarging upon these experiences. By making some of the soundmakers and the simply constructed musical instruments described in the following Activities,

the children will be able to achieve a better understanding of musical instruments as they employ the concepts of frequency, amplitude, and resonance that they have already mastered.

ACTIVITY 27 (y)

CLASSIFYING TOY MUSICAL INSTRUMENTS

Purpose: To show the wide range of devices that are used to produce varying types of musical sounds

Concept to be developed: Musical instruments create sound waves by means of vibrating surfaces, strings, reeds, bars, or air columns.

Materials needed:

Toy musical instruments: drum, ukelele, flute, harmonica, xylophone, etc.
Bulletin board and cards

INTRODUCTION: Show the children a photograph of an orchestra, or play a recording for them. Ask the children, "How many different musical instruments can you identify? In what ways are they different? Do they all produce sound waves in the same way?" Remind them of their experience with Activity 24, in which they learned how sound is made loud by means of soundboards in pianos, harps, violins, and other instruments. Review what they remember about soundboards and resonance. Then mention that loudness of sound is only one of its qualities and that there are many other interesting things to know about sound waves as produced by musical instruments.

Begin a collection of toy musical instruments and encourage the children to add some and to display them. Mount each on a bulletin board with a card asking, "What is the source of vibration? What is the method of playing? How does the musician change the frequency or pitch of the sound?" The children might find this information by looking at the instrument, observing someone playing it, asking people who know how to play it, reading in the library, etc.

When some of the children seem to have the information, lead a discussion to develop the answers to the questions. Help the children develop effective thinking and discussion skills: considering the ideas of others; discarding an answer when evidence shows another answer is better; considering answers carefully in the light of all that is known before accepting them. When the children find the answers to the questions, have them write the answers on file cards and post the cards next to each instrument.

Learnings: (x,y) Musical instruments may have vibrating strings, surfaces, bars, air columns, etc. (y) Sounds of higher pitch are produced by the shorter strings, the shorter reeds, the shorter bars, the shorter air columns, the smaller surfaces, the thinner strings, and the tighter strings.

ACTIVITY 28 (x,y)

MAKING A FILE BUZZ

Purpose: To show how the pitch of a sound may be altered

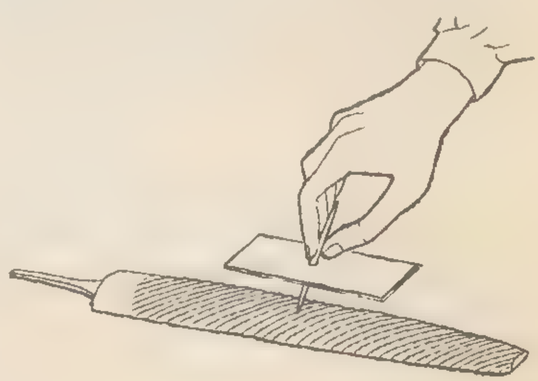
Concept to be developed: The pitch of a musical sound depends upon the frequency of the vibration it produces.

Materials needed:

File, coarse, flat, 8 inches or longer
Card, 3 by 5 inches
Toy siren
Toothpick

INTRODUCTION: Turn the handle on the siren slowly and ask the children to describe the sound the siren makes. Then turn the handle more quickly and ask the children to describe the sound produced. Finally, turn the handle as quickly as you can and ask the children to describe the sound. Ask the children, "When was the pitch the highest? When was the frequency of the sound waves the greatest? How else can we show that the pitch is the highest when the frequency is greatest?"

Punch holes in the card and insert the toothpick through them as shown below. Have a child draw the toothpick over the file. What do the children hear? *(A buzzing sound.)* What is the sound like? *(The pitch may vary from a high shriek to a low buzz depending on the speed of moving the toothpick.)* What vibrates to produce the sound waves? *(The card mounted on the toothpick.)* Let them experiment by moving the toothpick over the file at different speeds. Do they discover differences in the sounds? *(The*



faster the toothpick and the card are moved, the higher the pitch.) Ask the children, "What does it sound like when it is moving fast? when it is moving slowly? Can you feel any difference in the frequency of vibration of the toothpick and the card at fast and slow speeds?"

Discuss other experiences in which they could discover that high or low frequency of vibration makes sound of high or low pitch. *(Pitch is the property of sound associated with the frequency of the vibrating body and sound waves it produces.)* Mention that various pitches are associated with such sounds as the buzz of a saw on wood, the whine of snow tires on the road, the hum of a sewing machine, the purr of a cat, and the roar of racing cars. Help the children list sounds they can hear in a chart using two headings: high-pitch sounds and low-pitch sounds (perhaps a third heading, "medium-pitch sounds," might also be included).

Learnings: (x) High-pitch sounds are made by rapidly vibrating objects. (y,z) Rapidly vibrating objects have high-frequency vibrations and produce high-frequency sound waves that the ear senses as high pitch.

ACTIVITY 29 (x,y)

EXPERIMENTING WITH RUBBER BANDS

Purpose: To show the properties of the sounds produced by vibrating strings

Concept to be developed: The pitch of the sound produced by a vibrating string depends upon its tension, its length, and its thickness.

Materials needed:

Box, wood or plastic, about the size of a cigar box
Rubber bands of various sizes and thicknesses
Guitar or other stringed instrument

INTRODUCTION: Show a guitar to the children while you pluck the strings. Allow the children to hear what happens when you shorten the length of the string (by placing your finger on it), or increase or decrease the tension on it (by turning the tuning peg). Ask the children if they can suggest a method of making a simple stringed instrument that they can experiment upon.

Children who try to make simple musical instruments often attain the extent of involvement that characterizes meaningful learning. One child may make an instrument and demonstrate it to the class. Others may want to make one and form a band.

A rubber-band "ukelele" demonstrates the principles of varying pitch in stringed instruments. Have children listen as a child plucks one rubber band stretched across the open box. They will hear the change of pitch when the rubber band is stretched tighter. Have a child stretch a thicker rubber band alongside the other, stretching both bands so that they have about the same amount of tension. Have children listen and compare the pitches produced when each string is plucked. *(The thinner one should have the higher pitch.)* Try pressing a ruler lightly on the rubber bands, a short distance from one end, so that the length of rubber band that can vibrate is shortened. Compare the pitches of sound produced with the ruler in place and when it is removed. *(The pitch is higher when the rubber bands are shortened by the ruler.)*

Have the children select and adjust several rubber bands on their "ukeleles" to play "Three Blind Mice," or some song the class has learned. The music teacher might help them.

Learnings: (y) The pitch of a vibrating rubber band is higher when the band is stretched tighter, when it is thin, and when it is shortened. (y) High pitch is associated with vibrating objects and sound waves of higher frequency.

ACTIVITY 30 (z)

MAKING A TWO-STRING GUITAR

Purpose: To show how steel "strings" can be made to vibrate in musical instruments

Concept to be developed: The pitch of the sound produced by a vibrating string depends upon its length, its tension, and its thickness.

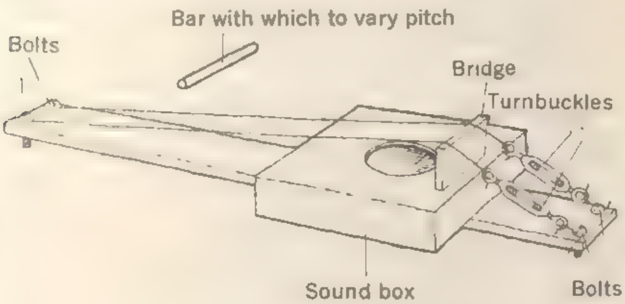
Materials needed:

(Most of the dimensions are not critical, so other sizes may be used.)
Board, oak preferred, 3 feet long, 6 inches wide, 1¼ inches thick with two ¼-inch holes bored through each end
Sound box, about 10 inches wide, 12 inches long, 2 inches deep (may be made of soft wood): 2 pieces 10 inches long, 1½ inches wide, ½ inch thick; 2 pieces 11 inches long, 1½ inches wide, ½ inch thick
Plywood: 2 pieces, 12 inches by 10 inches, ¼ inch thick with a 3-inch round hole cut in the plywood top
Steel wire, two 4-foot lengths, one heavier than the other
2 turnbuckles, 3-inch size
40 nails, 1-inch brads
Cement, household or pliobond
4 stove bolts, ¼-inch round head, 2 inches long

Bridge of wood, 4 inches long, $1\frac{1}{2}$ inches wide, $\frac{1}{2}$ inch thick
Playing bar of pipe or metal bar, 4 inches long.

INTRODUCTION: The construction of a "guitar" should lead to further learnings about the ways musicians produce the pitches with stringed instruments. Some of the children may also use their knowledge of musical scales and the piano keyboard to tune the guitar and to learn to play melodies.

In assembling the guitar, the children should follow the sketch below. Be sure that the two wire strings are about 2 inches apart. They are fastened to the bolts and to the turnbuckles by looping around twice and twisting 1 inch of the wire tightly around itself. The turnbuckles are then fastened to the bolts with short lengths of the wire used for strings. The sound-box bottom board may be nailed and cemented to the long board. The bridge is held in place only by the strings.



Have the children tune the strings to the pitches desired by tightening the turnbuckles. Have them play the guitar Hawaiian style by sliding the heavy metal bar or pipe or a knife handle along the strings to make varying musical pitches.

How does sliding the metal bar change the pitch? Why? *(As the bar is moved closer to the bridge, the pitch is raised because the string is shortened.)*

Perhaps you will want to have some children find information in the library and from other sources about professional guitars and other stringed instruments. Lead the children to compare ways of making changes of pitch in tuning and playing this guitar with the ways used in professional guitars, violins, pianos, and harps. Have them document their statements with quotations from their readings.

Learnings: (y) The pitch of a string is higher when it is thin or light, when it is tightened, when it is shortened. (y) When the Hawaiian guitar bar is moved toward the bridge of the guitar, the length of the string vibrating is shortened and its pitch becomes higher.

ACTIVITY 31 (y,z)

LEARNING ABOUT THE PIANO KEYBOARD

Purpose: To introduce the musical scale and its relationship to pitch

Concept to be developed: The musical scale is a set of pitches that "sound right" when played together.

Materials needed:

Piano

INTRODUCTION: Musical scales have developed gradually through intermediate stages to the present ones used in music. The children's need for a convenient pitch standard for tuning their homemade musical instruments may provide the natural lead into this study.

Using the piano keyboard, explore the key of C musical scale with the class. Play and sing do (*c*), re (*d*), mi (*e*), fa (*f*), sol (*g*), la (*a*), ti (*b*), do (*c′*) in the key of C. Have the children see that these are the white keys on the keyboard. See if they can tell when a "wrong" note or pitch (black key) is sounded in playing the C scale. Have them learn and sing the letter names of the white keys. Play "Mary Had a Little Lamb," "Twinkle, Twinkle Little Star," "Three Blind Mice," "Taps," and other simple melodies. Try singing the letter names of the piano keys instead of the words in these songs. Point out that the last note in most melodies played in the key of C is the note do (*c*). Have the children sing the C scale in octaves above and below the middle of the keyboard. Have the children discover that any melody may be played in the key of C in any octave, high or low, on the keyboard.

Perhaps you can work further with the music specialist to help those children with technical questions and with growing musical interests.

Learnings: (x,y) A musical scale is a set of pitches that "sound right" together. (y) The pitches in musical scales have syllable names (do, re, etc.). (y) The piano keys have letter names (*c*, *d*, etc.). (y) In the key of C, *c* is do. (y,z) Instruments may be adjusted or tuned to sound the pitches in a musical scale precisely.

ACTIVITY 32 (z)

TUNING STICKS OF WOOD

Purpose: To show how vibrating bars may be made to produce a desired pitch

Concept to be developed: In some musical instruments vibrating wooden bars are tuned to produce a desired range of pitches.

Materials needed:

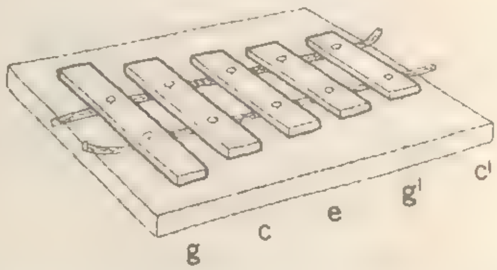
- Board, 10 inches square
- Soft wood, about ½ inch by 1 inch and about 6 feet long
- Clothesline, 2 feet long
- Piano, for tuning reference
- Half-round file or rasp
- Hand drill
- Saw, fine tooth
- Nails, thin, 1½ inch

INTRODUCTION: In the xylophone and similar instruments the source of the sounds is a set of vibrating bars. Review the concept of musical scales the children developed in the last Activity and point out to the children that musical instruments must be tuned so as to be able to produce the proper pitches. Ask the children, "Just as we were able to increase the pitch of a vibrating string by shortening it, do you think we would be able to increase the pitch of a wooden bar in the same way?"

In preparing to make a xylophone, have the children learn to tune a wooden bar to the desired pitch. Have them saw three test bars of wood (6 inches long and about ½ inch by 1 inch in cross section works well). Lay the bars across two strips of clothesline to support them on the table top. When tapped with a pencil, the bars should make sounds of about the same pitch. Saw ½ inch off one of the bars. Then place it on the rope strips again and tap it. What happens to the sound? *(Its pitch becomes higher than the other two bars and becomes still higher if more is sawed off.)*

Now help the children discover how to lower the pitch of a bar. Have a child use a half-round rasp or file to make a groove across (the width) and half-way through the middle of one of the two 6-inch bars. Tap it. Does its sound change? *(Its pitch becomes lower than the other bar and becomes still lower if the groove is made deeper.)*

You may want to help the children make a xylophone with pitches matching the pitches of the piano notes *g, c, e, g′*, and *c′* (an octave higher). Have a child saw a bar 10 inches long. Tap it and listen as he plays a series of piano keys to find the key to the pitch nearly matching the pitch of the bar. Then, by grooving across the bar or by sawing a little off its end, tune it lower or higher as needed to match the *g* note on the piano. To match *g* an octave above, saw a bar to a size about three fourths of the *g* bar. Then tune its pitch slightly higher or lower to exactly match *g′* on the piano. Have the child saw the other three bars, *c* shorter than *g*, *e* shorter than *c*, and *c′* shorter than *g′*. After the bars for the five pitches are cut and tuned, make two ⅛-inch holes in each with a hand drill. Drill the holes at a distance of one fourth the bar's length from each end of the bar. Fasten the bars to the base board on two strips of clothesline with nails hammered through the holes (loose fit) and through the rope as illustrated.



Children may play bugle calls, "Taps," "Reveille," "Assembly," and other simple melodies on the five-bar xylophones. They may wish to add other bars in order to play other melodies.

Learnings: (x,y) Short bars have higher pitches than long bars. (y,z) The longer bar vibrates with lower frequency. (x,y) The pitch of a bar may be made lower by filing a groove across the middle of it. (y,z) The groove weakens the bar, so that, when struck, it springs back with less force and thus vibrates with lower frequency than before.

ACTIVITY 33 (y,z)

TUNING SPRING CHIMES

Purpose: To show that metal bars may be tuned in the same way as wooden bars

Concept to be developed: In some musical instruments vibrating metal bars are tuned to produce a desired range of musical pitches.

Materials needed:

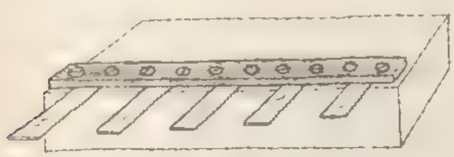
(Sizes are not critical.)

- 1 piece of wood ½ inch by 1 inch by 12 inches long
- 1 piece of wood ½ inch by 1 inch by 12 inches long

6 thin, round-head screws, 1 inch long
2 hacksaw blades (may be used blades or may be old clock spring or even coat-hanger wire)
Pliers
Screw driver
Hand drill
Piano (reference for tuning)

INTRODUCTION: Review with the children the concepts developed in the last Activity. Point out to them that the pitch of wooden bars was varied by shortening them or carving grooves in them. Ask the children, "Do you think the same methods could be used to tune an instrument that has metal bars? What would be the best way to find out?"

The spring "chimes" are short lengths of springy metal such as hacksaw blade, clock spring, or coat-hanger wire. Have a strong child use pliers to cut or break five 3-inch lengths of hacksaw blade or get the school custodian to help with this. Then, using the hand drill, have him make six holes, larger than the screws, about 1 inch apart in the ½-inch by 1-inch wood. Screw this along an edge of the 2-inch by 4-inch base, using the six screws. Leave the screws loose and insert a 3-inch piece of hacksaw blade in each space between screws as illustrated. Help the children discover the method of tuning the pieces of hacksaw blade to sound the pitches desired. To get the various pitches, have the children "pluck" each blade with a toothpick or matchstick, or tap it with the eraser end of a pencil. Do not handle blades with fingers, since the ends of the blades may be sharp. Ask the children to



answer the following questions: "How can you make sounds with the blades? How can you make the pitch higher? lower?" Have children test their answers. Lead them to see that shortening the amount of blade extending from between the two wooden pieces makes a sound of higher pitch.

You may have a child tune the blade at the left end to the same pitch as the *g* note on the piano. Adjust its length so that about 2 inches extend. Pluck it and then play a series of notes on the piano to see which one matches the pitch of the blade. Then adjust the length of the blade to make its pitch higher or lower to match the piano *g* note. Each of the other blades should extend slightly less to match the higher pitches, *c*, *e*, *g'*, and *c'* as they sound on the piano. Tighten the screws when the blades are in tune.

Encourage the children to play the spring chimes and the xylophone (Activity 32) together. Both have ranges suitable for playing "Taps," "Reveille," and other bugle calls. Some of the children may construct chime sets of more than five pitches to play more complex melodies.

Learnings: (x) Sound is produced when springy bars are plucked. (x,y) Shorter bars produce higher pitches than longer ones. (x,y) Lengths of metal bars do not sound the same pitches as wooden bars of the same lengths.

ACTIVITY 34 (y)

MAKING SODA STRAW "OBOES"

Purpose: To show that some musical instruments produce sounds by means of vibrating reeds

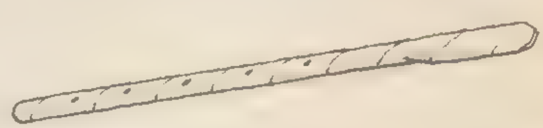
Concept to be developed: The vibrating reeds cause the column of air in the instrument to vibrate, and the frequency of this vibration determines the pitch.

Materials needed:

Soda straws
Scissors
Sharp knife

INTRODUCTION: In saxophones and in some other wind instruments the musician blows to cause a reed to flutter or vibrate. The air in a tube is made to vibrate by the reed. The vibration frequency most easy to produce is determined by length of the column of air in the tube. (It may vibrate at certain other frequencies but not so easily!) In other musical instruments, such as oboes, the sound is made by two reeds vibrating together. In this Activity the children will make little oboes out of soda straws to see how the "double reeds" vibrate to make a sound.

To make soda straw oboes, have the children obtain several soda straws of different materials and diameters, all cut to the same length. To form



the reed, flatten about ½ inch of one end and trim the corners of the folds as shown. Have a child

place the end of the straw well into his mouth, without touching his tongue on the reed, and blow. Do all the straws blow with the same pitch? *(Yes.)* Have him try blowing very hard and very softly. Does this change the pitch? *(Several pitches may be produced, but the one most easily produced should be the same for all straws that are of equal lengths.) Note:* Children should be cautioned to blow lightly and with a steady stream of breath. The little "reeds" need just the right amount of air passing through them at a constant rate for sound to be produced. Children should keep trying until they discover this "best adjustment" of air and speed of blowing. This will vary for different children. Next, use a sharp knife to cut a hole near the middle of the "oboe." Then cover the hole with a finger and blow. What happens to the pitch? *(The pitch is unchanged.)* What happens when the hole is open? *(The air column, between reed and hole, is only half as long and the pitch is about an octave higher.)*

Cut other holes to make the desired pitches. Let the children try covering all the holes. What is this pitch like? *(Lowest.)* What is the pitch when all the holes are uncovered? *(Highest.)*

A slide-oboe is made, without holes, by splitting a second straw on one side and rolling it so it fits into the oboe, like a trombone. Let the children try blowing the slide-oboe with the sliding straw all the way in. What is the pitch like? *(Highest.)* What is the pitch when it is as far out as it can slide? *(Lowest.)*

Learnings: (x) Two slender reeds at the end of a tube may be made to vibrate by blowing air rapidly through the tube. (x) High-pitch sounds are made when the length of vibrating air in the tube is short. (x,y) The length of the tube of vibrating air may be shortened by uncovering holes in the tube or by sliding a telescoping part of the tube.

Suggest that the children try to find more about wind instruments: How is the length of the tube or column of vibrating air changed in the clarinet? the trumpet? the trombone? How are the lips used in place of a reed in the brasses? Information may be obtained from the library, the music specialist, children who play an instrument, and other musicians.

ACTIVITY 35 (z)

MAKING A FLUTE

Purpose: To show that in some musical instruments a column of air vibrates without a vibrating reed.

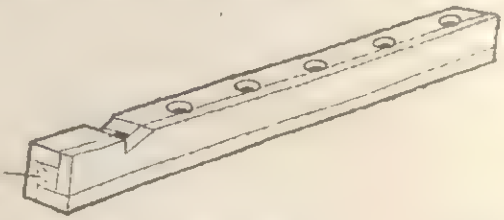
Concept to be developed: The pitch of the sound produced by some musical instruments is determined by the frequency of vibration of a column of air.

Materials needed:

- 4 strips of soft wood (balsa or pine) ¼ inch by ¾ inch by 12 inches (Sizes are not critical.)
- 40 thin nails, ¾-inch brads
- Plastic clay
- Knife
- Hand drill
- Hammer
- Saw, fine tooth

INTRODUCTION: The flute is a wind instrument in which there is no reed. Instead, the air inside vibrates because a stream of air flutters in and out of a carefully formed opening. Review the concepts developed in the previous Activity in which the children made the soda straw oboes. Ask the children, "Do you think we can make a column of air vibrate without using a 'reed'?"

A child can nail the four wood strips together to form a tube 12 inches long with a ½-inch square hole through it. About 1 inch from one end, he should saw across one side of the tube until the saw enters the inside of the tube. Then, 2 inches from the end, he should saw across the tube, but on a slant toward the first saw cut to remove a wedge-shaped block of wood as shown. The end of the tube near the saw cuts must be plugged with plastic clay. Next, it would be best



if the teacher used a thin knife blade to shape the top surface carefully so it directs a narrow stream of air toward the sharp edge of the hole made by the saw cuts. Explain to the children that when properly directed, the air stream will flutter up and down past the sharp edge, making the air column in the tube vibrate and producing a certain pitch. To change the pitch, show them that finger holes, about ¼ inch or larger, should be drilled. Have a child drill the first hole about half way between the saw cut and the end.

How does it sound? *(With no finger covering the hole, it will raise the pitch about one octave*

—the vibrating air column is only half as long.) Other holes may be drilled (or plugged) to produce desired pitches. Help the children discover that no matter how many of the holes are uncovered in fingering, the pitch corresponds to the length of the air column from the saw cut to the nearest *uncovered* hole. The lowest possible pitch is sounded when fingers cover all the holes.

Learnings: (x) Sound can be produced when air is blown past an opening in a tube (the air stream flutters in and out of the opening), such as in whistles and flutes. (x,y) High pitches are made by short tubes; holes are bored in a flute to make various pitches—when all the holes are uncovered, the pitch is high.

ACTIVITY 36 (x)

HEARING TONE QUALITY DIFFERENCES

Purpose: To show that in addition to differences of pitch, musical instruments also produce sounds with different qualities

Concept to be developed: Two sounds of identical pitch (frequency) may have different tone qualities, that is, one may be more pleasing to the ear than the other.

Materials needed:

Noise-makers: wood blocks, sandpaper, rubber bands, drinking glass, scissors, siren, paper, pans, whistle

Musical instruments: Piano, guitar, violin, trumpet, bell, harmonica, xylophone, mandolin, saxophone

INTRODUCTION: Turn the handle on the siren at a constant rate so that a steady high-pitched wail is produced. Then try to find the note of the same pitch on the piano. Ask the children, "Did both sounds appear to have the same pitch? Which sounded more pleasing to your ear?" Encourage the children to differentiate between the concepts of pitch and tone quality. Ask them if they think that the quality of a sound helps to identify the instrument that produces it. Have them suggest ways to test this idea.

You can help the children set up a testing situation for the class by taping a cardboard screen, about 1 foot high, along three edges of a table. Place the noise-makers behind the screen and have a child sound one at a time, holding it so the other children cannot see. Have the children try to identify the noise-maker and tell how they knew which each was. Ask the children, "What word describes its sound?" *(Encourage the use of such words as* rasping, scratchy, ringing, twanging, banging, knocking, rapping, thumping, hissing, clicking, whistling, piercing, mellow, metallic, full *or* rich, thin *or* small, *etc.)* Do these words mean the same as loudness and pitch? *(Most of the words suggested describe the quality of sound. Sounds of the same loudness or pitch may have different qualities.)* Help the children make a chart of words describing quality and the noise-makers having these qualities.

The children can try a similar test using musical instruments. Sound the same pitch at about the same loudness with each. Can they hear the difference? *(Yes. This is harder, but each has a quality of its own.)*

Learnings: (x) We recognize many sounds because of their quality. (x,y) Quality of sound is not loudness or pitch but is described by such words as *ringing, hissing, rasping,* etc.

ACTIVITY 37 (y,z)

EXPERIMENTING WITH OVERTONES

Purpose: To show that the tone quality of sound is a result of overtones produced by the vibrating body

Concept to be developed: Overtones are secondary sound waves produced by a vibrating body in addition to the primary (or fundamental) sound waves. Overtones have a higher frequency and lower amplitude than the fundamental pitch.

Materials needed:

Guitar

INTRODUCTION: Show the guitar to the children and discuss its strings. Review with them the fact that a string can vibrate just as the metal wires did on the two-string guitar they constructed in Activity 30. Now present the idea that a string can vibrate in different ways—that it can vibrate as a whole and also in parts. Demonstrate the vibration of the string by plucking one on the guitar and having the children listen carefully to the sound. (It will not matter if the guitar is not tuned properly.) When they have the sound well in mind, continue with the Activity.

Have a child pluck one of the strings of the guitar. While it is vibrating, have him rest a finger gently on its midpoint. What do the children hear? *(The pitch that was sounding will stop and in its place a low amplitude overtone, one octave higher, will be heard.)* Explain to the children that the overtone was really there all the time, but that the fundamental pitch obscured it because of the higher amplitude of the waves. Show

STRING VIBRATING AS A WHOLE

STRING VIBRATING IN TWO PARTS

STRING VIBRATING AS A WHOLE AND IN TWO PARTS SIMULTANEOUSLY

them that when a finger is placed at its midpoint, the string cannot vibrate as a whole, but that the two halves continue vibrating because the finger is at a "node"—at a point that is motionless as the halves vibrate. To test this again, have a second child do the same things with the other strings. Try it several times with each string, so that all the children can hear how overtones sound.

Point out to the children that the string can be made to vibrate in smaller parts than halves. Ask them to suggest a smaller fraction that might be tried. Elicit the suggestion that the string might be tested in thirds, rather than halves, as the next smaller fraction.

Have a child rest his finger at other nodes as follows. When his finger is on a spot one third of the string's length from the end, an overtone higher than the one heard previously will be sounded, since each third of the string continues to vibrate; when his finger is one fourth of the string's length from the end, each fourth of the string vibrates at a pitch two octaves higher than the fundamental pitch, etc.

The quality of sound is determined by the proportion of overtones present. Since the size and shape of the vibrating sound source and sound box or soundboard are different in the various instruments, the pitches and amplitudes of their overtones differ, causing the distinguishing qualities of their sounds.

Learning: (y,z) A string (and other objects) may vibrate as a whole or in parts, producing overtones. Overtones are of higher frequency and lower amplitude than the fundamental pitch.

ACTIVITY 38 (x,y)

MAKING ADDITIONAL INSTRUMENTS FOR A CLASSROOM BAND

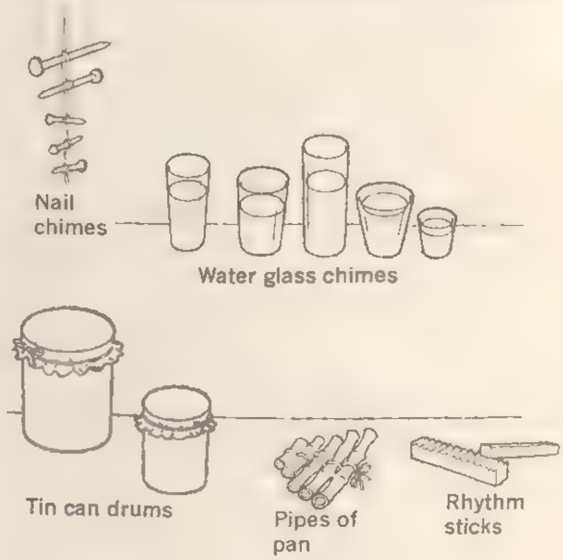
Purpose: To reinforce the concepts the children have learned while working with musical instruments

Concept to be developed: Different musical instruments can produce sound waves that sound well together.

Materials needed:
- Heavy paper (shopping bag)
- Inner-tube rubber
- Hollow reeds or bamboo
- Water glasses
- Nails
- Tin cans
- String
- Sticks

INTRODUCTION: To add to the children's knowledge about musical sound and how it is produced, suggest that they make some additional instruments in order to form a classroom band. Other musical instruments the children can make are shown below. The construction of these may be varied, using available materials and following the children's suggestions. Use the instruments in ways that help the children reinforce some of the ideas they have experienced about sound and pitch.

To show that different materials make different kinds of sounds, have the children listen to the tinkling of the nail chimes, the ring of the glasses,



the thump of the paper drum heads when struck with pencil drumsticks, the clatter of rhythm sticks, and the whispering sound made by blowing across the pipes of Pan (the bamboo or hollow reeds).

To illustrate that some part of the instrument must vibrate to make sound waves, have the

children try to sound various instruments while the vibrating part is held so that it cannot move. For example, have them touch the drum head and the rhythm stick while these are sounding and feel the vibration.

To demonstrate that greater energy must be applied to make the sound louder, have the children strike, pluck, or blow the various instruments with different forces and compare the loudness.

To show that high-pitched sounds are produced by short tubes of air, have the children compare the pitches of the various-length pipes of Pan by blowing across each. To show that high-pitched sounds are made by taut drum heads, have the children strike the drum head while pressing on one side, near the edge, to make it taut (be careful not to tear the paper). To show that high-pitched sounds are made by rapidly vibrating objects, have a child move the rhythm stick over the notched stick at various speeds. He can feel the faster vibration and hear the higher pitch when the stick moves faster.

Suggestions to extend the children's experiences with musical instruments: Some of these may be used to follow up leads suggested by the children to find more information or to sum up ideas in the study of sound energy. Others, while related to the sound energy theme, may help develop the children's language skills, effective work habits, and resourcefulness.

- Help the children compose accompaniments for rhythm activities and songs, using their instruments.
- Let the children plan to dramatize a story incorporating their learnings.
- Ask music students or professional musicians to help answer some of the children's questions.
- Listen to phonograph records of instrumental music and try to identify some of the instruments.
- See instruments from the school band and compare their construction and method of playing with the homemade ones.

Summing Up Ideas: In this section children will have learned that musical instruments produce sounds in different ways. They have participated in activities that show that some instruments produce sounds by means of vibrating strings; others produce sounds by means of vibrating surfaces, vibrating reeds, and vibrating columns of air. They have learned now that some part of the instrument must vibrate to produce sound waves. In addition, they have discovered an important relationship between air and its rate of vibration. The longer the column of air that vibrates or the greater the frequency of vibration, the higher the pitch; the shorter the column of air or the lower the frequency of vibration, the lower the pitch.

DO SOUND WAVES TRAVEL THROUGH MATERIALS OTHER THAN AIR?

In the preceding sections all the concepts studied dealt with sound waves traveling in air. There is nothing unusual in emphasizing this means of sound transmission, for obviously the vast majority of the sounds that reach our ears do so by traveling through the air.

However, despite the children's greater familiarity with sound waves traveling through the air, it is, nevertheless, important to develop the idea that sound waves also travel through many other substances. Before developing the concept that materials other than air can transmit sound waves, it may be useful to review the way longitudinal waves travel through springs and other items. An important point to emphasize is that as long as there are particles of any sort present that can move against one another, longitudinal waves can be transmitted. The children should be reminded of this point and of their previous experiences with how longitudinal waves travel in preparation for the following Activities.

ACTIVITY 39 (x)

HEARING SOUND THROUGH WOOD

Purpose: To show that sound waves travel through wood

Concept to be developed: Longitudinal waves can be transmitted through any material that has particles that can move against one another.

Materials needed:

Table, 3 or 4 feet long
Window stick, clothes prop, yardstick, or other long wooden stick
Tuning fork

INTRODUCTION: Have a child place his ear against one end of a table. Have another child scratch or tap his fingernail on the other end of the table. The child with his ear against the table should hear the scratching or tapping clearly through the table top. Repeat this until all the children have had

a chance to listen. Then ask the children, "Why can you hear the sound through the wood? What kind of a sound wave would send a noise through wood?" Encourage their theories and then mention that perhaps some answers can be found in the following Activity.

With his ear at one end of a yardstick or longer stick, have a child try to hear soft scratching and tapping sounds made at the other end. Hold a vibrating tuning-fork handle against the other end. Have another child hold the other end of the stick against his throat as he talks or hums. Have them tell what happens and ask them to explain why. *(The energy of the vibrating objects is transmitted as sound waves through the wooden stick. The sound waves come through with little loss of amplitude, for they spread out very little. The children will discover that the sound heard is louder when the stick is held lightly, for then less of the sound energy is transferred to their hand.)*

Learnings: (x) Sound waves travel through wood. (x,y) Actions that produce sound waves in the air can also produce sound waves that travel through wood. (y,z) When sound waves spread out or when some of their energy is converted into other kinds of energy, the waves have lower amplitudes, that is, the sound is softer.

ACTIVITY 40

MAKING SOUND TRAVEL THROUGH A STRING

Purpose: To show that sound waves can travel through a string

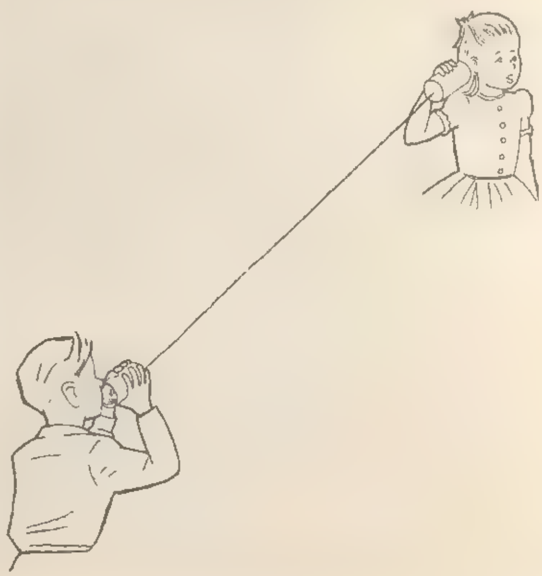
Concept to be developed: Longitudinal waves can be transmitted through any material that has particles that can move against one another.

Materials needed:

String (light, strong twine is best.)
2 oatmeal boxes (paper cups or tin cans)
Metal teaspoon

INTRODUCTION: Tell the children that, although they have found that sound waves can go through wood, there may be other solid materials that can carry sound waves. Ask them to suggest some through which they think sound waves might go, and tell why. Then tie the center of a 3-foot length of string around the handle of a metal teaspoon. Allow the teaspoon to swing freely against the edge of a desk and ask the children to describe the clinking sound produced. Then have each of the children wrap an end of the string around each index finger and, after placing the fingers in his ears, allow the spoon to swing freely against the edge of the desk. After all of the children have done this, ask them to describe the sound they heard. Ask the children, "Why did we hear a ringing, musical tone through the string but not through the air?" Remind the children about what they have learned concerning vibrating strings and harmonics. Mention that the following Activity will help them find an answer to the question.

Have the children punch a small hole in the bottom of each oatmeal box. Help them lead the ends of the string through the holes into the two boxes. Next, have a child tie a matchstick to each end so it can't pull out of the hole. Now stretch the string reasonably taut and have two children use the oatmeal box "telephone" by taking turns listening and talking. One child should hold his finger lightly on the string while another child talks. Can he feel the disturbance traveling through the string? Have a child put a finger on the oatmeal-box bottom. Can he feel the oatmeal-box bottom vibrate? Let the children try different kinds of string and wire and different boxes, paper cups, and cans. What do they discover in using different materials? *(Some materials conduct sound waves better than others.)* Does touching the string affect the amount of sound conducted? *(Yes. The sound is not as loud.)* Have several children try to talk around a corner. What happens to the sound? Why? *(The sound can hardly be heard because most of the motion of the string is stopped where it touches the walls or objects forming the corner.)*



Learnings: (x) Sound travels through stretched string and wire. (x,y) Little sound gets through the string when hands or other objects touch it.

ACTIVITY 41 (x)

DISCOVERING WAYS TO HEAR DISTANT SOUNDS THROUGH MATERIALS

Purpose: To show that sound travels through many solid objects

Concept to be developed: Sound travels through many solid materials more easily than it travels through air.

Materials needed:

No special materials are necessary.

INTRODUCTION: Suggest to the children that many of the following Activities may be tried at home.

Some of the uses of sounds that travel through solid materials are very old but fun for children to try:

Tap a signal on a water pipe. Can it be heard upstairs? downstairs? next door?

When the washing machine is running, put your ear against a door frame in the house. Can you hear the washing machine?

Put your ear to the ground or to a smooth tree trunk or to an electric service pole. You can hear sounds such as children running and street cars approaching, sounds of heavy trucks, mill machinery, pile drivers, and other heavy sounds that travel through the ground.

Touch the handle of a vibrating tuning fork to the top of a child's head. Is bone a good sound conductor?

Learning: (x) Sound travels through many solid materials more easily than through air.

ACTIVITY 42 (x)

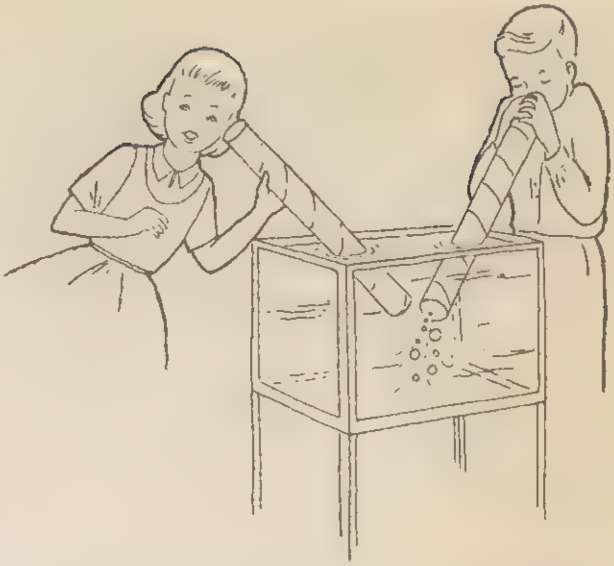
TESTING WATER AS A CARRIER OF SOUND

Purpose: To establish the idea that sound may travel through water

Concept to be developed: Sound waves can travel through water with varying degrees of clarity.

Materials needed:

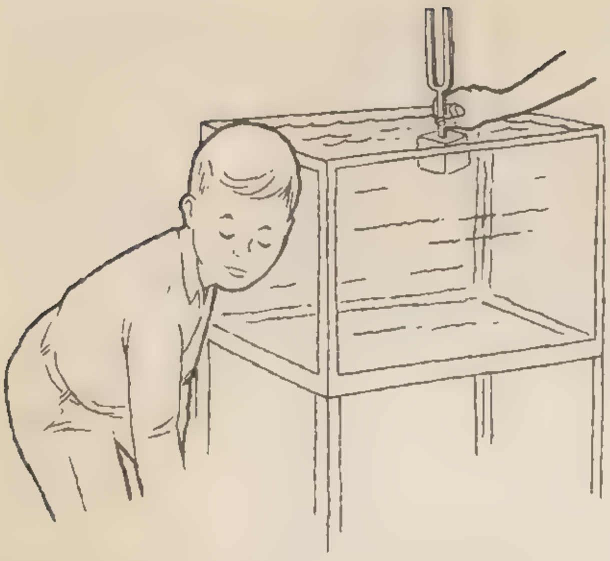
2 pieces of garden hose or 2 cardboard tubes, 1 to 3 feet long
Aquarium full of water
Tuning fork
Block of wood, about 4 inches square



INTRODUCTION: Having discovered that sound waves will travel through solids, such as wood and string, the children can now proceed to test whether the waves will travel through other materials. Ask them what other materials they can think of to test. Ask the children, "If one child were in a wooden boat that was floating in a lake or river and he were to tap out a message with his foot against the bottom of the boat, could someone swimming underneath the boat hear the message?" The children know that sound waves travel through wood from their experiences in previous Activities, but may not know how sound travels through water. Encourage the children to share their ideas about this. Have them share their underwater swimming experiences. Some children may have heard the motor and propeller noises of a passing motorboat, the splash of a diver, the movement of stones and waves on the beach. Some may mention that talking underwater sounds like gargling. Suggest that the following Activity may help to answer some of the questions they may have about underwater sounds.

Have a child cup his hands around the end of a cardboard tube to form a seal so he can talk into the tube without allowing air to escape. Then place the other end of the tube underwater in an aquarium. Another child may place one end of a second tube in the aquarium and the other end to his ear. When the first child talks have the others observe the bubbles appearing at the submerged end of his tube. Does the second child hear the sound clearly? Why? *(He hears an indistinct sound—like gargling. The bubbles deflect and distort the sound waves.)*

Have a child float a large block of wood in the aquarium, being careful not to let it touch



the sides. Let him place his ear against one side of the aquarium. Then have another child bring the handle of a vibrating tuning fork down to touch the floating wood block. Does the sound go through the water? *(Yes. There is no distortion this time because there are no bubbles.)*

Learning: (x) Sound waves travel through water, although they may be distorted by bubbles.

ACTIVITY 43 (y,z)

TESTING CARBON DIOXIDE AS A CARRIER OF SOUND

Purpose: To show that other gases besides air can transmit sound waves

Concept to be developed: Sound travels through air and through other gases that we cannot see.

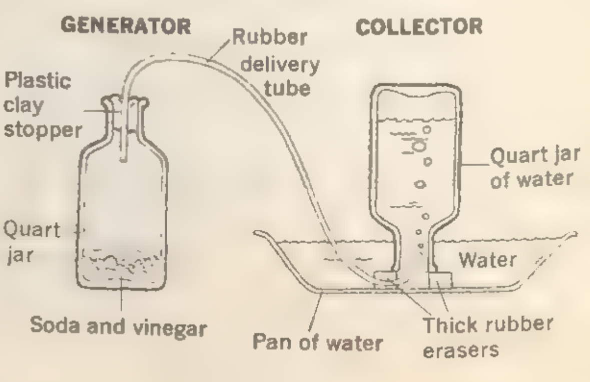
Materials needed:

- 2 quart bottles
- Vinegar
- 2 thick rubber erasers
- Coat-hanger wire
- Plastic clay
- Baking soda
- Rubber band
- Bell
- Rubber tubing, 3/16 or ¼ inch inside diameter, 2 feet long
- Shallow baking pan, 2- or 3-quart size

INTRODUCTION: After the children have completed Activity 42, ask them about other materials that sound waves might travel through. Remind them of the situation of the boy in the boat, with which Activity 42 was introduced. Ask the children, "If the boy in the boat shouts something to a friend on the shore, will his friend hear him?" When they answer, "Of course," ask them if they know through what material the sound must travel to get to the boy on the shore. When they say, "Air," ask if anyone knows what kind of material air really is. Is it a solid like wood? Is it a liquid like water? Discuss with them the idea that air is a gas, and suggest that it might be interesting to see if sound will travel through other kinds of gases. Explain that even though we cannot see air (and many other gases) we can show that a gas is present by a simple Activity. Point out that we can also manufacture certain gases and collect them. We can do this, for example, with carbon dioxide, which is one of the gases that make up the air we breathe. Once the carbon dioxide is collected, it can be used in a test to see whether it will conduct sound waves.

Several children can work together to collect enough carbon dioxide for experimenting. Explain to them that they will need a "gas generator" (the apparatus in which the gas is produced) and a "pneumatic trough" (an apparatus in which the gas may be collected by the displacement of water), both of which should be assembled as in the illustration. The gas generator is a quart bottle with a plastic-clay stopper that seals a rubber tube in the bottle. The pneumatic trough is a 2- or 3-quart pan, half-filled with water, with blocks to hold the collecting bottle off the bottom. The 1-quart collecting bottle must be inverted while full of water and set into the trough so that it is resting on the blocks. To invert the full collecting bottle into position, have a child cover the mouth of the bottle with a stiff card, invert the bottle while holding the card in place, lower it until the mouth is under the water in the trough, and then slide the card off. The water should not run out, but the children who plan to do this will need some practice.

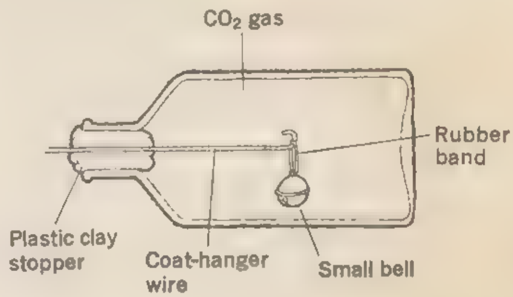
Next, explain to the class that carbon dioxide, CO_2, is easily formed by mixing together two



substances that will react to form a new material different from either of them—a gas. This formation of a gas is called a chemical reaction, and in this case the reaction occurs when baking soda and vinegar are mixed together. (The children may have to try several times to find the amounts of vinegar and baking soda needed because differences in the materials and conditions change the reaction rate, amount of foam, etc.) They should place ½ cup of vinegar and 3 or 4 tablespoonfuls of baking soda in the generator-bottle, replacing the stopper quickly once bubbles begin to form. Have the children let the gas bubble out of the rubber delivery tube into the water for a few seconds without trying to collect any. Why? *(This clears the tube and generator of most of the air that was present.)* Then they should place the tube under the collecting bottle and allow the CO_2 bubbles to replace the water in it. (The CO_2 replaces the water because it is insoluble—that is, it does not dissolve in the water—and it is under great enough pressure to push the water out of the bottle.) When the bottle is full of carbon dioxide (when all the water has been driven out of the bottle), the stopper should be loosely inserted in the bottle to preserve the gas until the children are ready to experiment with it.

Explain to the children that they will have to find some way to test whether sound waves can travel through carbon dioxide. Elicit their suggestions as to what might be done. Perhaps someone will suggest putting a bell or some other little noise-maker into the bottle of CO_2. Then a discussion should be started on how to keep the gas from escaping. Suggest, too, that since they know that air is a gas, they use one bottle of air (one gas) and one bottle of CO_2 (another gas) so that they can make a comparison between the way each carries sound.

Have a child make a device called a sound conduction tester for use with CO_2 as in the drawing. To do this, he should push a rod of coat-hanger wire through some plastic clay that has been molded into a stopper, being sure the clay is tight around the rod so gases cannot escape around it. Attach a tiny bell or some other small noise-maker to a rubber band and tie the rubber band to the end of the rod. The noise-maker should hang freely but not be able to strike the sides of the bottle. Next, have a child put the stopper and noise-maker in a bottle of air, and try shaking the bottle to see how loud the noise-maker sounds in it. Then, of course, have him try the stopper and noise-maker in the CO_2. He should be careful to transfer the stoppers carefully and quickly to avoid losing CO_2 from the bottle and letting air into it. When the bottle of CO_2 is shaken, the class should hear the noise-maker. They may notice a difference in the loudness of sound coming through air and CO_2. Why?



(Various materials, including gases, transmit sound energy in different amounts. Explain that the carbon dioxide and the air are made out of tiny particles that are moved against one another as the bell vibrates. Review with the children how longitudinal waves travel and emphasize to them that the energy given to the particles in the gas by the vibrating bell is carried from particle to particle as a sound wave.)

A variation of this test may be made by filling one small plastic bag with CO_2 by attaching the bag to the delivery tube. Fill another plastic bag with air by blowing into it. Then as each bag is held to a child's ear, have him listen to a ticking watch or to scratching and tapping sounds on the other side of the bag. (They should hear the sounds both through the air and through the CO_2.)

Learning: (x) Sound travels through air and some other gases that we cannot see.

ACTIVITY 44 (y,z)

TESTING THE POSSIBILITY OF SOUND TRANSMISSION ON THE MOON

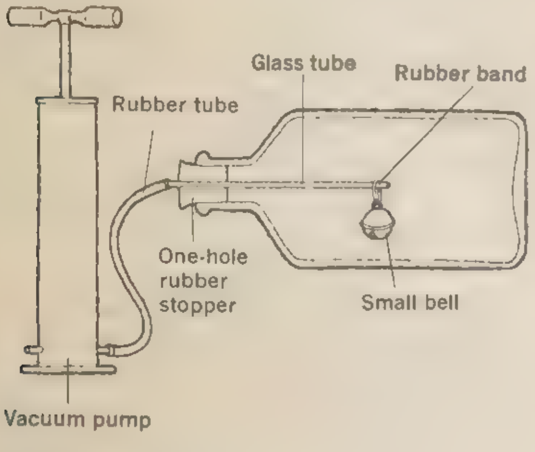
Purpose: To show that sound cannot travel where there are no particles to be disturbed

Concept to be developed: Sound waves cannot originate in a vacuum, that is, where there is no material or medium in which the waves can be propagated.

Materials needed:

½-gallon bottle (round like a bleach or starch bottle)
1-hole rubber stopper (to fit the bottle)
Glass tubing, 8 inches long
Rubber tubing, 2 feet long
Vacuum pump (a small hand-type pump may be borrowed from a high school physics teacher or purchased for $6 or $7 from a laboratory supply house)
Bell

INTRODUCTION: The previous Activity may easily lead a child to ask the question "Will sound travel where there is no air or other gas?" Another child, having read that there is no air on the Moon, may wonder, "Will sound travel on the Moon?" Indicate to the children that the same equipment that was used in Activity 43 might be used in finding the answers to these questions. Ask the children, "How can the same equipment used to collect gases and test their ability to conduct sound be used in an experiment to find out what happens when no gas is present?" Ask them how they would go about removing the CO_2 from the bottle. If a child suggests pumping it out, have the children proceed with the Activity.



Have the children set up the vacuum pump, bottle, and bell as in the illustration.

Before pumping out the air with the vacuum pump, shake the bottle and ask the children to listen to the sound of the bell as it comes through the air and glass of the bottle. Then have a child start pumping the air out of the bottle while another child continues to shake the bottle. What happens? *(The sound becomes softer and softer because the air particles are becoming fewer and farther apart.)* Review the fact that this shows that if there are no particles to move against one another, longitudinal waves (the sound waves) cannot be transmitted. When the sound is no longer heard, quickly remove the rubber tubing from the stopper. Does the sound seem to return as the child continues to shake the bottle? Why? *(The air particles that transmit the sound waves return.)*

Help the children develop further skill in critical thinking as you lead them to discuss such questions as: Was all the air out of the bottle when no sound was heard? *(No, but very little was left.)* Was there *absolutely* no sound at any time? *(No. Usually the children can hear it faintly.)* What is the purpose of the rubber band suspending the noise-maker? *(Rubber is a good soundproofing material and conducts very little of the sound.)* What happens to the *energy* of the noisemaker when it can't go outward as sound? *(It is converted mostly to heat energy in the bell and rubber band, but it is such a small quantity that the children cannot feel it.)*

Learnings: (x) Sound cannot travel through empty space. (y,z) Sound travels in longitudinal waves by the longitudinal movement of particles. Where there are few particles, few sound waves can be produced. (y,z) If the Moon has little or no air, little or no sound can be heard.

Added Activities: Library research is another way children can investigate sound in space. You may want to emphasize the need to find up-to-date reading, to check authors' qualifications, to resolve contradictions found in writings, etc., as children try to answer questions about current space exploration:

Is there air in space? Is there air on the Moon? What is the atmosphere? How high does our atmosphere extend? Is there air in the astronaut's capsule? How will astronauts communicate on the Moon? These questions are answered in different ways by different authors. Help the children become open-minded in considering the different answers. Help them become critical in demanding that the author state his reasons or evidence for his statements, or that he make clear that his statement is an opinion that needs further testing.

Summing Up Ideas: In this section the children should have been led to understand that many different substances can transmit sound waves. Sound waves can be transmitted through solids, liquids, and gases. The children should be able to realize now that not all substances transmit

sound equally well and to state that solids are the best conductors of sound waves. In addition, they now have seen that no sound is transmitted in a vacuum (an absence of air or other gas) because in a vacuum there are no particles to compress and expand as waves.

HOW DO SOUND WAVES CAUSE ECHOES?

Although the concept that sound waves travel through a wide variety of substances is very important to our understanding of sound, there are other experiences with sound that must be explained by other means. For example, what causes an echo?

To answer this question, we must introduce another concept, one of reflection and absorption. Perhaps it might be presented to the children in this way: Although we have seen that sound waves travel through many different substances, there are some substances the waves cannot penetrate. What happens to the sound waves then? Ask for the children's ideas about what happens when sound waves encounter an unusually hard surface, such as a mountain or a brick wall. Point out that such a substance reflects sound waves, that is, most of the sound waves that hit a reflective surface bounce off in another direction. Then ask them to imagine the opposite, a very soft substance such as a rug or a heavy curtain, and to theorize about what takes place when sound waves hit these. Explain that these substances absorb sound waves, that is, the sound waves do not bounce off these surfaces but are soaked up in the same way that water is soaked up by a sponge. The children may understand that a simple analogy to this would be to throw a rubber ball against a brick wall and against a canvas target; the ball bounces off the wall back to the thrower, but drops to the foot of the canvas (because its energy has been absorbed).

ACTIVITY 45 (x,y)

INVESTIGATING ECHOES

Purpose: To show that echoes are caused by sound waves returning to their place of origin

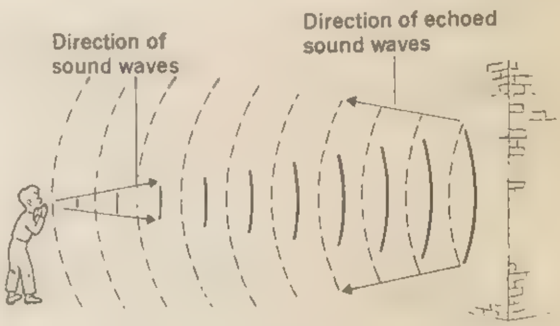
Concept to be developed: Some hard surfaces can reflect sound waves.

Materials needed:

Tin cans
Clapping boards

INTRODUCTION: Tell the children about the Swiss yodelers, who sing notes of varying pitch in the Alps and then wait for the echo to repeat the yodel. Ask the children, "What do you think the echo is? Why do the sounds return to the yodeler?" Have the children suggest ways of producing echoes and try some of them.

Most buildings with a large, flat wall reflect good echoes (even if the wall has lots of windows, but it is better if these are closed). Take the class outside and have a child stand far enough away from the wall (200 or 300 feet) so the sound will require a noticeable time to travel to the wall and bounce back to him. In order to hear the echo, he must stand directly in front of the wall, not off to either side. Have different children



try many kinds of sharp, distinct sounds: clap their hands, clap two boards, strike a large tin can, shout short sounds like "tic-toc".

To get a rough idea of how long it takes the sound to go to the wall and return, see how many rapid hand claps can be made before the echo is heard. Listen after each trial for the number of claps that echo back. Calculate the fraction of a second that each hand clap represents by counting the number of very rapid claps made during five seconds. The fraction of a second for each hand clap is

$$\frac{5}{\text{the number of claps.}}$$

For example, if a child can clap twenty times in five seconds, each hand clap represents $5/20$ or $1/4$ second.

Learnings: (x) Part of the energy of sound waves striking a hard, flat surface may be converted to sound waves traveling back toward the source as echoes. (y,z) Echoes sound weak because not all the energy is returned and sound waves spread, losing amplitude, as they travel.

A blind person hears and uses echoes of the tap of his cane and the sound of his shoes on the pavement to help guide him when he walks. He can tell by the sound of the echo how near he is to a wall or, if there is no echo, that there is no wall near him.

ACTIVITY 46 (y)

TESTING MATERIALS THAT ABSORB SOUND

Purpose: To show that although some materials reflect sound waves, others absorb them

Concept to be developed: Some materials soften or deaden the sound made by a vibrating body by a process called absorption.

Materials needed:

- Tuning fork
- Rubber striker
- Small pieces, ⅛ inch thick or more, or several layers to make ⅛-inch thicknesses of these: rubber (inner tube), cork, fiber mat or board, sponge, cotton padding, felt

INTRODUCTION: Review with the children the concept of the reflection of sound waves in Activity 45. Ask the children, "Do all materials cause the sound waves to bounce away as echoes? What can we do if we want to cut down the echoes in a room?" Some of the children may have had previous experience with sound absorption concerning high-fidelity and stereophonic equipment, or the soundproofing of rooms in their homes. Have them share these experiences with the other children. Ask the children, "How can we test a material to see whether or not it absorbs sound waves well?" Encourage their suggestions about methods and materials to use.

Children can test the sound-absorbing property of small pieces of rubber, sponge, felt, and other materials. Place the piece to be tested on a wooden table top, strike a tuning fork, and bring its handle down on the piece of material. Then strike the tuning fork again and touch its handle to the bare wood top. Which is louder? Try each material. Are the results the same? Why? *(Many soft materials tend to "soak up" the energy of sound and other vibrations. Rubber, sponge, soft fiber board, and some loosely woven cloths are used as sound absorbers to soundproof rooms and machines. The energy of sound waves is not destroyed but is converted into heat in these materials, although it is usually not enough heat to feel.)*

Learnings: (x) Some materials soften or deaden the sound made by vibrating objects. (x,y) Soundproofing materials are used on shoe soles, ceilings, and auto and airplane parts to soften the sounds made or echoed by them. (z) Conservation of energy principle: The sound energy is not destroyed, but is converted to heat.

ACTIVITY 47 (x)

LISTENING IN A SOUNDPROOF BOX

Purpose: To show how sound-absorbing materials may be used as soundproofing materials

Concept to be developed: Sound absorption prevents sound waves from either entering or leaving an area lined with an absorbing material.

Materials needed:

- 2 cardboard boxes, 20 inches long by 12 inches wide by 12 inches deep
- Cotton padding or other soundproofing material to line the box
- Paste or staples
- Noise-makers: bell, sandpaper and wooden block, ticking clock

INTRODUCTION: Review the last Activity with the children. Point out to them that they showed that some materials absorbed vibrations better than others. Ask the children, "Do you think that a good sound absorber could be used to make a room soundproof?" Encourage the children to theorize about this idea, and ask them to suggest ways to test the soundproofing materials.

To show sound absorption another way, obtain two boxes—cardboard, wood, or tin—of the same size, and line one with cotton padding or other soundproofing material as shown in the illustration. Then have a child listen to various sound sources inside each box: a clock ticking, a bell ringing, a file or piece of sandpaper rubbed

over a wooden block. Let a child put the box over his head and listen. What room noises can he hear? How do the noise-makers (bell, sandpaper, clock, etc.) sound? Have the children make a list of places in your classroom or in the school where soundproofing would be helpful.

Learnings: (x) Some materials can be used to soften or deaden sounds. (x,y) Soundproofing materials are used to soften undesirable sounds and echoes in auditoriums, telephone booths, and schoolrooms.

Summing Up Ideas: Sound waves bounce off some materials. This causes echoes. Other materials soak up the sound waves and convert their energy into heat. These materials are used to deaden the sound in rooms and are called soundproofing materials.

IMPORTANT IDEAS IN THIS CHAPTER

For the kindergarten, primary, and intermediate grade children, the kinds of ideas with the most meaning or application are these:

- That sound waves are like the waves in Slinky toys and in a row of falling dominoes.
- That sound waves are made by vibrating objects.
- That sound waves from different objects can have different frequencies (pitches) and amplitudes.
- That sound waves travel through solids, liquids, and gases but not through empty space.
- That sound may be echoed or reflected by some materials and absorbed by others.

In the intermediate and upper grades the children should be led to develop concepts that are more complex and quantitative:

- That vibrations that cannot be measured directly can be recorded on moving disks or can be calculated.
- That sound wave characteristics are quantitative and interrelated and may be expressed as equations.
- The conservation of energy principle: that the energy in sound waves was converted from some other form of energy and may be converted to another form of energy.
- That careful work is required to make accurate measurements of fast vibrations and high speeds.

Of the many discrete concepts that have been mentioned in the work of this chapter—the ones so necessary to success in constructions and demonstrations using sound waves—there is one that is especially significant in all the branches of science: **energy is conserved**—it cannot be created or destroyed but can be changed from one form to another. Energy occurs in sound waves, vibrating bodies, electric fields, magnetic fields, and in other forms. You can help children gain deeper understanding of this conservation principle by encouraging questions about where the various energy forms occur in the ear and brain, in the record players and sound recorders, and in the playing of musical instruments. Some of the energy-change sequences will make interesting sentence charts. Some can be illustrated in drawings and in labeled diagrams.

4

INVESTIGATING MAGNETISM, ELECTRICITY, AND ELECTROMAGNETISM

Electromagnetic waves are perhaps the most versatile of the energy wave forms. Although children may not realize it, they are very familiar with electromagnetic energy, for they come into contact with various forms of it each day. Their experiences have introduced them to heat, light, radio and television waves, radar, and X rays, all of which are electromagnetic waves. However, before the children can understand the concepts of electromagnetism, they must first obtain a thorough understanding of the twin forms of energy, electricity and magnetism, that are associated with it.

The experience and scope of interest children bring to the study of electricity, magnetism, and electromagnetism are shown by the questions they ask:

"Why do I get a shock from my comb when I rub it against my trousers?"

"Where does the electricity go when I turn off the light?"

"Why does my magnet pick up paper clips but not pennies?"

"Can I make a magnet from this iron bar?"

"How does an electromagnet work?"

The children will find the answers to these as you help them to develop the concepts necessary to understand electricity, magnetism, and electromagnetism. Perhaps the most difficult concept for the children to grasp will be that of a *field;* therefore, special emphasis must be placed upon this, for it would be impossible to study electricity and magnetism were it not for the detectable effects of electric and magnetic fields. Technically speaking, a field is a region or space traversed by lines of force, with the lines of force originating in, and extending around, certain objects. For the purposes of this book, however, we will consider these fields only as specific areas around sources of magnetic or electrical energy, areas in which the effects of the energy can be studied. An understanding of the concept of fields will help the children grasp these other concepts:

(x,y) Magnetic fields are located around magnetic poles.

(x,y) Electric fields are located around electric charges.

(y,z) Magnetic fields and poles can be produced by moving electrons.

(z) Electric fields and electron movements can be caused by moving magnetic fields.

(z) The electromagnetic (combined electric and magnetic) field extends outward from its sources and permeates space around and within objects.

(y,z) Electromagnetic waves are often produced when electrons are made to vibrate.

(z) The conservation of energy principle: Energy can be transformed from one form to another but cannot be destroyed or created.

As the concepts are developed, you will see ways to help the children develop orderly, effective ways of tackling problems and arriving at answers they are willing to accept—the open-minded, critical ways of coming to conclusions.

HOW CAN WE SEE MAGNETIC FIELDS?

Magnetic fields are comparatively easy to "see," and for this reason it is easier to add the concept of a field to the children's experiences if magnetic fields are studied before electric fields. Magnetic fields can be found about any magnetic body, regardless of the body's shape or size; magnetic fields are found around lumps of lodestone (naturally occurring magnetic "rocks"), horseshoe magnets, U-shaped magnets, and bar magnets. All of these are called permanent magnets because their fields cannot be turned on and off at will. Another type of magnet is the electromagnet. We can turn an electromagnet on and off whenever we please. While it is on it is surrounded by a field, but while it is off there is none. For this reason, we call an electromagnet a temporary magnet.

ACTIVITY 48 (x)

"SEEING" MAGNETIC FIELDS

Purpose: To show the existence of magnetic fields

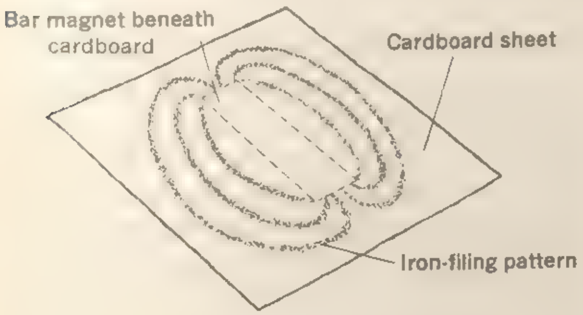
Concept to be developed: All magnets, regardless of their shape or size, are surrounded by magnetic fields.

Materials needed:

- Iron filings, ¼ pound or more
- Cardboard square, at least 12 inches square
- Jar with holes punched in the lid
- Bar magnet
- Horseshoe magnet
- U-shaped magnet
- Paper clips

INTRODUCTION: Place some iron filings on one sheet of paper and several paper clips on another sheet of paper. Using one end of a bar magnet, pick up some of the iron filings; using the other end of the magnet, pick up some of the paper clips. Ask the children, "Why were we able to pick up the iron filings and the paper clips with the magnet?" Encourage the children to phrase their answers in terms of "something" at the end of the magnet attracting the iron filings and clips to the magnet.

The easiest way to show the pattern of the field about a magnet is through the use of iron filings. Iron filings are light in weight and move easily in a magnet's field. They can be sprinkled like salt from a jar with holes punched in the lid. Place a square of stiff cardboard flat on a table and sprinkle iron filings evenly over it. The cardboard should be at least 1 foot square. Place a bar magnet flat on the table and slowly lower



the filing-sprinkled cardboard over it. The children should notice how the iron filings move as the cardboard is brought closer to the magnet. Let the cardboard rest on the magnet and support it so that it is level. Use clay, blocks, erasers, pencils, or books, but nothing made of iron or steel as supports. Tap the cardboard very gently several times. Notice the shape of the pattern caused by the magnet's field.

Repeat the Activity, using horseshoe and U-shaped magnets (and possibly even a chunk of lodestone if you can get it) in place of the bar magnet. What do you observe? *(Regardless of the shape of the magnet, the magnet's field always has a similar pattern and extends between the ends of the magnet. We call these ends the poles of the magnet.)*

Can one magnet's field affect another's? *(Yes.)* Try placing several magnets together under the cardboard and filings. See what happens to the pattern of the field when the positions of the magnets are altered relative to one another.

Learnings: (x) Magnetic fields surround magnets. (x) Magnetic fields have a characteristic pattern. (x) Magnetic fields always extend between the two poles of the magnet. (y) Moving one magnet close to another causes changes in their magnetic-field patterns.

ACTIVITY 49 (x,y)

TESTING THE STRENGTH OF MAGNETIC FIELDS

Purpose: To show that the strength of magnetic fields varies from magnet to magnet and grows weaker as their distance from the magnets increases

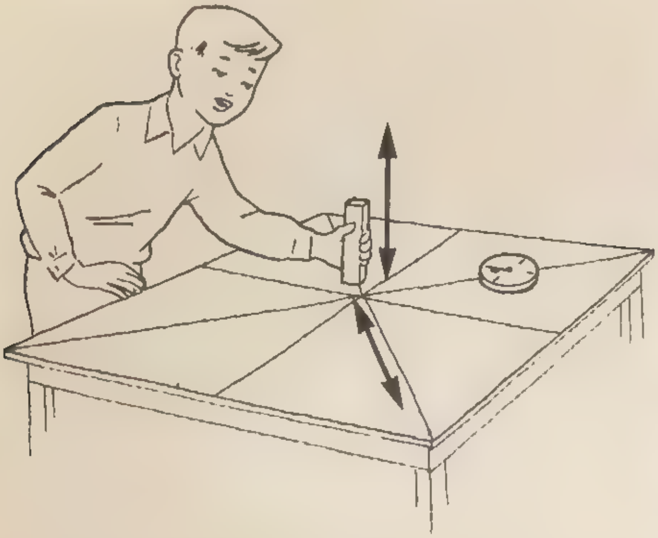
Concept to be developed: The strength of a magnetic field diminishes as its distance from the magnet increases.

Materials needed:

- Compass, Boy Scout or miniature
- Paper (about 30 inches square)
- Bar magnets of different sizes
- Horseshoe magnet
- U-shaped magnet

INTRODUCTION: Have the children gather in small groups around the science table. Mention that now that they have discovered what a magnetic field is they can find out more about what it is like. Push a bar magnet slowly across the desk toward a paper clip until the clip is attracted to it. Ask the children, "How far away from the paper clip was the magnet when the magnetic field began to attract the clip? Is the magnetic field as strong far away from the magnet as it is close to the magnet? How can we test to see how strong the magnetic field is?"

On a 30-inch square of paper have a child draw diagonal lines and lines through the center from side to side and top to bottom as in the drawing. Place the compass near the center on one of the lines and place one end of a bar magnet on the center. Have children notice how the compass needle is disturbed when the magnet is moved back and forth along the line that



crosses the line on which the compass is resting. What happens to the compass needle when the magnet is moved up and down over the center? *(If the magnetic field around the magnet is strong enough, the compass needle will be deflected as the magnet is moved. The magnetic field becomes weaker as the distance from the magnet is increased.)* Leaving the magnet at the center, have a child move the compass, little by little, farther out from the center and test often to see if moving the magnet disturbs it. Mark the place on the line under the compass where the magnet's field no longer disturbs the compass needle. Have a child repeat this procedure on each line and then join the marks with a heavy line.

On the same sheet of paper or on separate sheets, encourage children to plot the extent of fields around poles of other magnets. Ask the children, "How do you think the extent of fields would differ if the magnet were on its side so both poles were on the paper?" Let them try to plot this. Also, let them try plotting the extent of fields around horseshoe magnets and other types.

It may stretch your children's thinking some if you raise and discuss questions such as these: Do the lines we draw mark the end of the field about the magnet or do they just mark the place beyond which it is too weak to detect? *(It marks the place beyond which the magnet's field is too weak to detect.)* Is there a magnetic field around the compass needle? *(It is a magnet.)* Does the strength of the compass needle's field have anything to do with how far you can detect a magnet's field? *(Yes. A surveyor's fine compass detects autos passing many yards away.)*

Learnings: (x) Around a magnet's pole is a region in which magnetic materials are attracted. This region is said to be a magnetic field. (y) Magnetic fields are strong near magnet poles but weaken rapidly as the distance from the poles is increased. (y) Moving one magnet close to another causes changes in the strength of their magnetic fields.

ACTIVITY 50 (y)

TESTING MAGNETIC FIELD PENETRATION IN MATERIALS

Purpose: To show that a magnetic field passes through most materials

Concept to be developed: Only materials that can themselves be magnetized, such as iron and steel, cannot be penetrated by magnetic fields.

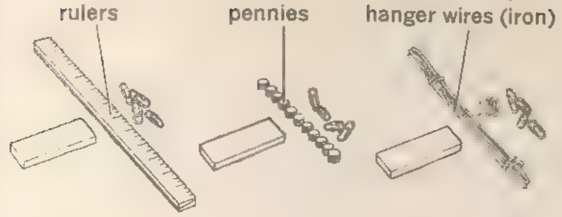
Materials needed:

- Strong magnet
- Paper clip
- Cardboard, 12-inch or larger squares
- Iron filings, ¼ pound or more
- Materials to test: plastic rulers, wood rulers, pencils, brass rod, iron bar, glass, cardboard strips, cloth, clay, rubber, copper coins, etc.

INTRODUCTION: Have the children gather in small groups. Say, "Let's see what else a magnetic field will do." Have one of them hold a plastic ruler between a paper clip and a strong magnet (the ruler should be held close to the paper clip) so that the long edge of the ruler rests on the desk. Slowly move the magnet toward the paper clip until the clip is attracted toward it (but is stopped by the ruler). Ask the children, "Will the magnetic field pass through any barrier? Let's test some other materials."

Have the children arrange a barrier of the material to be tested near one pole of the magnet. Barriers about the same thickness as the magnet may be formed of layers or piles or bundles of the material as in the drawing. Have children take turns testing each one by placing the filing-sprinkled cardboard and the magnet on opposite sides of the barrier. The amount of movement of the filings will indicate whether the magnetic field is "blocked" or otherwise disturbed. You may wish to suggest anchoring the magnet and iron bar with plastic clay if the magnetic field is very strong.

Test all the above materials and whatever additional ones your children will suggest. Let them carry out their own ideas for making the barriers to test. After testing a variety of materials, they should find that no material except



iron, steel, nickel, and cobalt has any noticeable effect on magnetic fields of force. Help them recognize the significance of iron as a magnetic-field blocker. Mention as an example the fact that nonmagnetic watches are simply fitted with iron shields near critical springs, which would not function properly if magnetized.

To extend the children's concept of magnetic shielding you may want to suggest the question "What would the iron filings do if the magnet were surrounded by a long bundle of coat-hanger wires?" Try it. *(Very little if any magnetic field extends beyond the ring of iron.)*

Learning: (y) Magnetic fields easily penetrate all materials except iron, steel, cobalt, and nickel. (The U.S. five-cent (nickel) coin is 75% copper and only 25% nickel; therefore, it is penetrated by magnetic fields. The Canadian nickel, however, is 100% nickel; therefore, it cannot be penetrated by magnetic fields.) Soft iron rings or cases are used to shield watch and delicate instrument parts from magnetic fields.

ACTIVITY 51 (x,y)

MAGNETIZING IRON AND STEEL

Purpose: To show that iron and steel objects can be made into magnets

Concept to be developed: Magnetic fields can be induced in iron and steel objects.

Materials needed:

Bar magnet
Paper clips
Steel ruler
Iron filings
Large needle
Iron or steel nails
Cardboard, at least 12 inches square

INTRODUCTION: Take two identical iron or steel nails and, before beginning the Activity, magnetize one of them as described below. Then show the two nails to the children. Holding one nail in each hand, bring them slowly toward a pile of iron filings. When the magnetized nail has attracted some iron filings to it, ask the children, "Why did this nail attract the iron filings? Can we make the other nail into a magnet also? How?"

Have a child rub a large iron or steel nail with a bar magnet. It is important to note that the *same* pole of the magnet must be used for each stroke and that each stroke must be made in the *same* direction. Do not let the child rub with a back-and-forth motion! Let the child press gently and rub slowly. When he is ready to begin a new stroke, have him lift the magnet away from the nail and come back to his starting point before touching the nail again. After stroking the nail 30 to 35 times, the child should hold it over the iron filings and slowly lower it. What happens? *(The nail should attract the iron filings, for it should have been magnetized.)* Repeat the Activity using paper clips, needles, a steel ruler, and other objects the children may suggest. Try magnetizing objects that are not made out of iron or steel. Can they be magnetized? *(No.)*

Lower the cardboard square covered with iron filings over the magnetized nail as in Activity 48. Can the pattern of the magnetic field around the nail be seen? *(Yes.)* Is it the same as the pattern of the field around a bar magnet? *(Yes.)* Repeat this Activity using the other objects you have magnetized.

Learning: (x,y) Magnetic fields may be induced in iron and steel objects. These objects then become permanent magnets.

Summing Up Ideas: Magnetic fields extend around magnetized objects. Magnetic fields have a characteristic pattern, which always extends between the two poles of the magnet. Magnetic fields are strongest near the poles of the magnet, and they weaken as they get farther from the poles. Moving one magnet close to another changes the pattern and strength of their magnetic fields.

HOW CAN WE SEE ELECTRIC FIELDS?

After the above introduction to the basic idea of a field and of what magnetism is and does, the next concept to consider is that of the electric *charge*, since electric fields exist in the space around electric charges. All the things around us contain basic bits or pieces of matter, two of which we call electrons and protons. Electrons

may be thought of as bits of negative electricity, protons as bits of positive electricity. In the normal course of events the things around us contain equal numbers of protons and electrons, and thus, since they contain the same number of bits of positive and negative electricity, they are electrically neutral. If we transfer some of the electrons from one thing to another, one will have a surplus of electrons (more electrons than protons) while the other thing will have a deficiency of electrons (more protons than electrons). When something has a surplus of electrons, it has more bits of negative electricity than bits of positive electricity. Therefore we say that it has a *negative charge*. When something has a deficiency of electrons, it has more positive bits of electricity. Therefore it has a *positive charge*.

The following Activities will help children learn what an electric charge is, that it can be made and removed, that it is possible to detect an electric field, that there are various kinds of charges, and other related facts. The concepts explored briefly above, about electrons and protons, the negative and positive electrical "bits" which may be transferred from one thing to another, should be woven into the Activities.*

ACTIVITY 52 (x)

MAKING AND REMOVING ELECTRIC CHARGES

Purpose: To show that an electric field exists and in what ways it is different from a magnetic field

Concept to be developed: Free electrons can be transferred from one object to another to produce electrically charged bodies and create an electric field.

Materials needed:

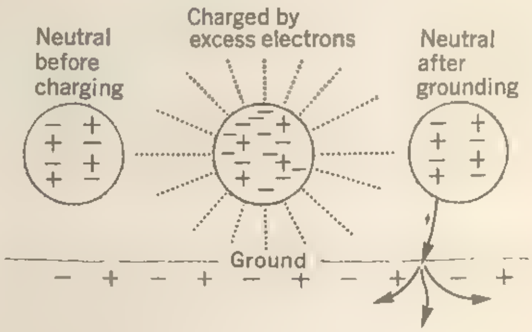
- Fur or soft wool cloth
- Hard-rubber or plastic objects: rods, pens, old phonograph records, combs, etc.
- Small pieces of material: bits of tissue paper, hair clippings, fuzzy seed parts, feathers, etc.
- Balloons
- Plastic bags
- Inflatable toys

INTRODUCTION: Ask one of the girls in your class to come to the front of the room. Rub a plastic or hard-rubber comb with a piece of fur or a soft wool cloth. Bring the comb slowly toward her hair. Ask the children, "Why is her hair attracted toward the comb? Is the comb surrounded by a magnetic field? If this is not a magnetic field, what can it be?"

* The concepts of matter and its electrical and particulate nature are developed in *Atoms and Molecules*, by Seymour Trieger (Investigating Science with Children Series; Darien, Conn., Teachers Publishing Corporation, 1964).

Have a child rub an inflated balloon briskly with fur or wool, then hold it against the wall or against another child's clothing. What happens? *(The balloon will stick to the wall or to the clothing.)* Have a child rub a comb with the fur or wool. Then bring it near bits of paper or small feathers. What happens? *(The bits are attracted and jump to the comb when it is held close to them.)* Let a child hold a sheet of paper against the flat, smooth wall and rub the paper briskly with the wool or fur. What happens when he tries to pull one corner away from the wall? *(The paper is attracted to the wall. When it is released, it snaps back against the wall.)* Try rubbing other objects and test their attraction for bits of paper. Point out that just as the children magnetized the nail by rubbing a magnet on it, so in this case they have induced one object to "become electric," or to become charged with electricity. The force attracting the noncharged things to the charged things is a kind of electricity. Then explain about electrons and protons, negative and positive charges.

To clarify the process of transferring electrons, put the following drawing on the chalkboard.



In the drawing a neutral balloon, having equal numbers of positive (+) and negative (−) charges, is at the left. Each (−) or (+) represents a huge number of electrons (−) or protons (+). In the center picture the balloon has been rubbed with wool or fur and has gained many electrons. (Wool, fur, and some other materials allow electrons to be rubbed off easily onto other materials.) Therefore the balloon is now charged by the presence of excess electrons and has an electric field around it. On the right the balloon has been "neutralized" by a grounding wire. The excess electrons were transferred into the ground, leaving the balloon neutral once again.

To illustrate the idea of the electric field, rub the fur or wool on a large inflated plastic bag or inflatable toy. Bring it near the hair on a child's arm or head. What does he feel? *(He should feel a tickling sensation as his hair is moved by the attraction of the charge.)* Explain to the children that the region of attraction is called an electric field. During a discussion of experiences with electric charges you may guide children to make their own definitions of *electric field*, such as "the space where you can feel the pull of a charged toy" or "the space full of the charged balloon's attraction."

Learning how to remove the charge from an object may be very revealing to children as they develop the concepts of electric charges and fields. After testing a charged object's attraction for bits of paper, have a child touch all parts of the object with his hands and test it again. Does the object attract bits of paper? Why not? *(There is no longer attraction, the charge is gone. The scientist's explanation for this is that the child's body, or any other large conducting object, is a huge reservoir of charges to which the addition or subtraction of a few electrons makes little change in the neutral balance of positive and negative charges.)* Bring out that the ground is the best charge neutralizer. It is for this reason that grounding wires, chains, or straps are used to neutralize charges on airplanes being fueled, autos, electric power lines, etc.

Learnings: (x) Some objects become electrically charged when rubbed with wool or fur. (x) Around an object that is electrically charged, there is a region of attraction for neutral objects. In that region an electric field is said to exist.

ACTIVITY 53 (x,y)

TESTING ELECTRIC FIELDS WITH PUFFED CEREAL GRAINS

Purpose: To show how electric fields may be detected

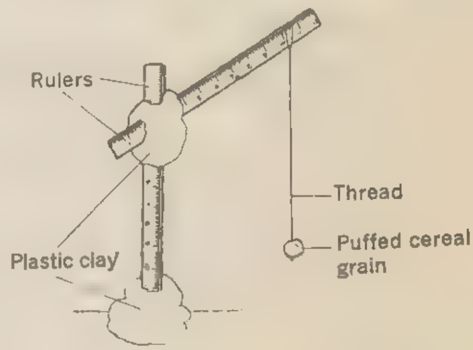
Concept to be developed: A neutral object is attracted by the electric field of a charged object.

Materials needed:

Thin sticks or rulers
Plastic clay
Aluminum foil
Thread
Balloons
Fur or wool
Hard-rubber (or plastic) comb or rod
Puffed cereal grains or pith balls

INTRODUCTION: Rub a hard-rubber comb or rod with a piece of fur or wool. Show it to the children and ask them, "How can we tell if it is surrounded by an electric field?" Encourage the children to suggest methods of testing for electric fields. Try their suggestions and see if they work.

Have a child construct a support of thin sticks and plastic clay as shown in the illustration. The puffed cereal grain or pith ball suspended by thread is very sensitive to the forces in electric fields. Let one child rub a hard-rubber comb or rod with the fur or wool. How can the puffed cereal grain be used to test whether the rod is charged? Let the children suggest ways to use it to find out where the electric field is strongest about the rod. They may simply bring the puffed



cereal grain close to various parts of the rod and observe how strongly it is attracted. *(It should be attracted least where the rod was rubbed least.)*

Let the grain touch and rub along the charged rod. What happens? Why? *(The ball should be attracted at first and then hop away and be pushed away from the rod. The cereal grain becomes charged with electrons transferred from the rod. Then you can make clear the important concept that objects with like electrical charges repel one another.)* Would a cereal grain covered with aluminum foil act the same way? Try it. *(Repulsion occurs more quickly because aluminum and other metals are good electric conductors, that is, electrons move readily through conductors.)* Try suspending two balloons, tied to long threads side by side. Rub each with the wool and have the children observe that there is some force pushing them apart. Test them by bringing the charged cereal grain near. Is the charged cereal grain a more sensitive indicator than when it was not charged? *(Yes.)*

In a discussion of these experiences, where objects that are charged alike so obviously repel,

you may lead children to make their own carefully worded statements related to the concept "like charges repel." For subsequent application, children should be encouraged to word their statements in terms of electric fields:

"The electric fields of similarly charged balloons push the balloons apart."

"The charged cereal grain is repelled in the electric field of a similarly charged balloon."

Learnings: (x) A neutral object is attracted by the electric field of a charged object. (x) Two objects that are charged alike have electric fields that cause them to repel each other. (x) A puffed cereal grain suspended by a thread is moved easily in an electric field.

ACTIVITY 54 (x,y)

SEEING THAT THERE ARE TWO DIFFERENT TYPES OF ELECTRIC CHARGES

Purpose: To show that there are two types of electric charges and that like charges repel each other whereas unlike charges attract each other

Concept to be developed: If an object has a surplus of free electrons, it is negatively charged; if an object has a deficiency of free electrons, it is positively charged.

Materials needed:

Hard-rubber comb
Glass rod
Thin sticks or rulers
Wool or fur
Silk cloth
Thread
Puffed cereal grains or pith balls
2 bar magnets

INTRODUCTION: Tell the children that for a moment you want to go back to using magnets in order to show them something else interesting about electric charges. Review with the children what they know about magnetic fields and about the poles of the magnet. Place the two bar magnets on your desk or science table so that they are about 12 inches apart and two poles are facing each other. Push one magnet slowly toward the other until the second magnet is either attracted or repelled. Then reverse the position of only one of the magnets so that its second pole is now pointing toward the other magnet. Starting the magnets out about 12 inches apart, again push one slowly toward the other. Ask the children to explain why in the first case the magnets were attracted to (or repelled from) one another and in the second case the opposite thing happened. Encourage the children to phrase their answers in terms of two different "types" of magnetic fields. Then ask them, "Do you think there are also two different types of electric charges?"

Suspend the puffed cereal grain from the wooden support as in Activity 53. Have a child rub the hard-rubber comb with the wool or fur and charge the cereal grain by touching it with the comb. Ask the children what they would expect to happen if the charged comb were now moved slowly toward the cereal grain. *(The cereal grain would move away from the comb, for like charges repel each other.)* Try it and see if what we would expect actually happens. *(It should.)* Ask the children what they would expect to happen if the uncharged glass rod were moved slowly toward the cereal grain. *(The cereal grain would be attracted to the rod, for as we saw in Activity 53 neutral bodies and charged bodies attract each other.)* Try it. *(If you try this several times, you will have to recharge the cereal grain each time it touches the rod, for it loses its charge when it touches the neutral body.)* Now have a child rub the glass rod with the silk cloth. Ask the children how we can tell whether the glass rod now has a charge on it. *(If we touch the rod to an uncharged cereal grain—thereby charging it—and rub the rod with the silk cloth a second time, when we bring the rod toward the charged cereal grain the cereal grain will be repelled. This shows that the cereal grain and the rod have like charges.)* Now have a child charge a cereal grain with a hard-rubber comb and then move the charged glass rod slowly toward the charged cereal grain. What happens? *(The cereal grain is attracted to the glass rod.)* Encourage the children to speculate about what this means. Let them try to devise ways of testing their explanations. Try to guide them to the correct answer by leading them through the following concepts:

Like charges repel each other; therefore, the glass rod and the cereal grain could not have had like charges.

Charged bodies attract uncharged bodies; but we know that both the rod and the cereal grain were charged. Therefore, the rod and the cereal grain must have had unlike charges.

Unlike charges attract each other.

Learnings: (x) There are two types of charges. (x) Unlike charges attract each other. (x) Like charges repel each other.

ACTIVITY 55 (z)

MAKING A LEAF-TYPE ELECTROSCOPE

Purpose: To construct a sensitive device for detecting electric charges

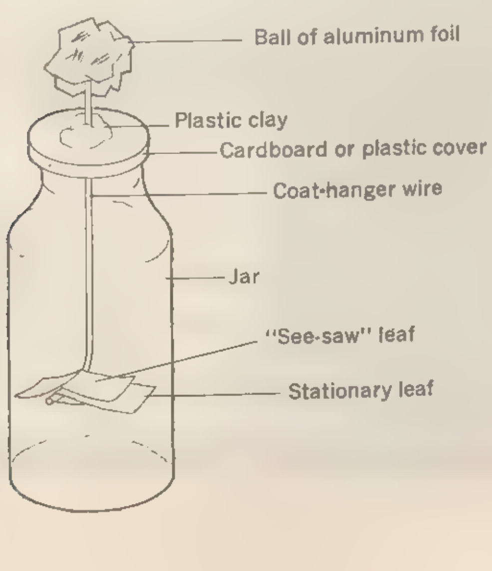
Concept to be developed: Electrons can be caused to move through metals or other conductors by electric fields.

Materials needed:

- Jar, wide mouth, pint or quart size with a plastic lid or cardboard cover
- Aluminum-foil wrap, about 4 inches square for the leaves and 1 foot square for the knob
- Coat-hanger wire
- Household cement or pliobond
- Shallow 10-inch pan
- Hard-rubber comb
- Wool cloth or fur
- Rubber sheet or mat
- Plastic clay
- Plastic bag
- Wire, 6 feet long

INTRODUCTION: Inflate the plastic bag and charge it by rubbing it with the wool cloth. Ask the children, "How can we tell whether the plastic bag has an electric charge?" They may say, "See if it attracts something that hasn't been rubbed. You rubbed the bag just as you rubbed the other things, so it must have a charge." But point out that these are not very scientific observations and that there should be a way to determine the answer more accurately. Try their suggestions and see which is the most sensitive method. Mention that now that they have found out that there are like and unlike charges in things, there is a device they can make to help them detect whether electric charges are present in various objects. This device is called an electroscope.

As the children assemble the electroscope as shown in the drawing, be sure that they scrape or sandpaper the coat-hanger wire clean of all paint and then cement the stationary leaf only at one outside edge so that the rest can touch the bare wire. Make sure the seesaw leaf moves very freely and is balanced so that the slightest force will move it. As the children use the electroscope, you may want to raise questions with them about the design in order to have them improve on it after making one. They could make others with leaves and knobs of various shapes and sizes and compare their sensitivity in detecting electric charges.



Rub the rubber comb or an inflated plastic bag with the wool or fur, and, to test it for charge, bring it near (but do not let it touch) the knob. *(The electric field of a charged object will repel electrons from the knob, down the wire, to the leaves, which, upon being charged with excess electrons, will repel each other causing the seesaw leaf to tilt.)* Observe what happens when the charged object is removed. Ask the children, "What will happen if the charged object *touches* the knob?" Try it. *(Electrons move from the charged object onto the electroscope causing it to be charged, and the seesaw leaf tilts, even after the charged object is removed.)*

When the electroscope does become charged, it may be discharged by touching the knob with a finger or with a wire that is attached to a grounded water pipe or faucet. When you are testing, be careful that you do not ground the charged object or the electroscope accidentally.

Suggest that one end of a 6-foot length of insulated wire, scraped bare at each end, be attached to the electroscope ball and that a metal pan (which is resting on a rubber sheet) be attached to the other end. What will happen when a large charged plastic bag is brought near the pan? *(The electroscope leaves separate.)* Why? *(The electric field of the charged bag causes electrons from the pan to move through the wire to the electroscope.)* Will the electroscope behave the same way if the pan is touching a hand or resting on the ground? *(No.)* Why? *(The electrons from the pan are moved through the easier path to the hand or ground.)* Discuss and test such situation problems with the children. Encourage them to cite references and previous experiences and to listen to one another's ideas in comparing and summing up. Help them develop these ways of careful, effective thinking.

Learnings: (x,y) An electroscope can be used to detect very weak electric fields. (y,z) Electrons can be caused to move through metal by electric

fields (as in the wire and in the electroscope).

For further investigation a discussion of ways to make the electroscope even more easily affected by electric fields may raise some suggestions worth trying. Which is better—large or small jar? long or short coat-hanger wire? more wire inside or outside the jar? larger or smaller leaves? larger or smaller ball on top? clay, wax, or cement support?

Encourage the children to give reasons and to cite evidence from their experiences and readings as they discuss these and other suggestions. Let them test any suggestions that are made.

ACTIVITY 56 (y)

MEASURING HOW FAR ELECTRIC FIELDS PENETRATE MATERIALS

Purpose: To show that an electric field can be measured and that it penetrates some materials but not others

Concept to be developed: Electric fields penetrate some materials more easily than others.

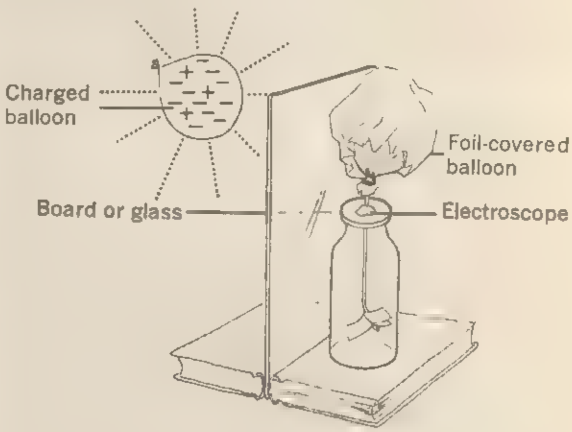
Materials needed:

Electroscope from Activity 55
Ruler
Wool or fur
Balloon
Aluminum foil
Rubber comb
Squares of material 1 or 2 feet square: glass, cardboard, wood, solid metal, metal mesh, etc.

INTRODUCTION: As your children have tried many of the preceding Activities, they may very logically have wondered about how far the electric field of a charged object extends. Encourage them to suggest ways this distance might be measured. Of course, to do this they will need a very sensitive indicator of electric field. Both the suspended cereal grain and the balloon were rather sensitive. The leaf-type electroscope is even more so when the seesaw leaf is carefully balanced.

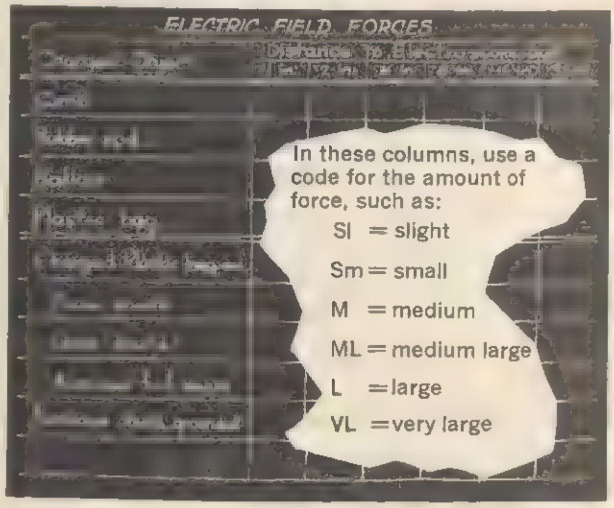
Have the children use the electroscope for this Activity, with the following suggestions. The children may find that a balloon covered with metal foil or a large piece of metal, like a pan, supported by clay and tape on top of the electroscope ball will increase the sensitivity of the instrument. They should measure with a ruler the greatest distances at which the electric fields of various objects such as a charged rubber comb or balloon make the leaves move. Children will notice how strong the electric field is when the object is close and how rapidly the strength of the field decreases with distance from the object.

Next, the children should also test how far electric fields can penetrate through materials other than air. To do this, they may place, as a shield, between the charged plastic bag and the electroscope ball, sheets of various materials: paper, glass, aluminum foil, plywood, cloth, window screen, shallow pan, etc. For each shielding material, they can measure the farthest distances at which the charged bag's electric field causes the electroscope leaves to move.



Children may ask, "Does it make a difference when the shields that are good conductors (such as metals) are connected by wire to a ground or are touching your hand?" *(Yes. The electric field does not pass through.)* Let the children try both ways as they carefully observe what takes place.

You can help the children plan and use a chart something like the illustration to record and organize their findings.



The planning of a way to record information in a manner useful for making comparisons and for reference is an activity that may develop skill in thinking carefully and in considering the ideas of others. Some of the critical questions that may be asked are these:

Is one trial at each distance enough?

Can we be sure the object is charged the same on each trial?

What units or code shall we use to record the electric-field strength?

Would our findings (data) be the same on any day? in any place? as observed by anyone?

Learnings: (y) Electric fields penetrate some materials more readily than others. (Grounded metal screens are used to shield delicate instruments from electric fields.) (z) Electroscopes may be made very sensitive to weak electric fields. (y) Electric fields are strong near charged objects but weaken rapidly as distance is increased. (yz) Careful planning, measuring, and recording are needed to make comparisons that are quantitative.

ACTIVITY 57 (x,y)

SEEING CHANGES IN ELECTRIC FIELDS

Purpose: To show the effects of interacting electric fields

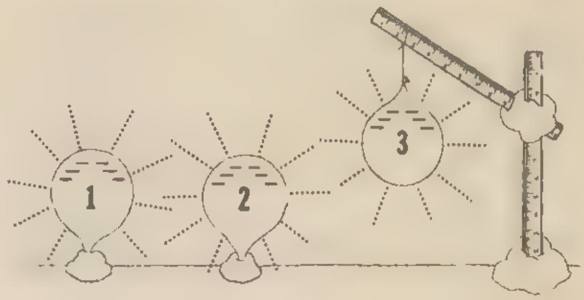
Concept to be developed: Changes in electric fields may cause charged object to move.

Materials needed:

3 balloons
Fur or wool
Thin sticks
Plastic clay

INTRODUCTION: Charge two balloons by rubbing them with the fur and place one of them against the wall. Move the other charged balloon close to the balloon that is stuck to the wall. Ask the children, "Why does one balloon keep moving away from the other?" Draw from them the idea that the two charges of the balloons are having some effect on each other, as they note that the balloon that is stuck to the wall behaves differently when the other balloon is brought close to it. The effect that one charged object has upon another occurs when the two electrical fields meet or act together. This process is called interaction.

To show this further, have the children mount and arrange three balloons as illustrated. Rub each balloon briskly with the wool and place



balloon No. 2 a few inches from suspended balloon No. 3. What happens? *(Balloon No. 3 is pushed away.)* Let one child bring balloon No. 1 close to No. 2 and move it slowly around No. 2, from one side to the other. Is the electric field near balloon No. 3 changing? Why? *(Balloon No. 3 should change its position slightly as the moving of balloon No. 1 changes the electric-field strength in various directions.)* Perhaps your children will suggest other ways they can use balloons or pith balls to test the effects of changing fields on a charged object.

Learnings: (y) Changes in the relative positions of two or more charged objects cause changes in their electric fields. (y) Changes in electric fields may cause charged objects to move.

ACTIVITY 58 (y,z)

MAKING A "GALVANOMETER" AND USING IT TO "SEE" ELECTRONS MOVE

Purpose: To construct a device that will indicate the flow of electrons through a wire and to use it to indicate this movement

Concept to be developed: A galvanometer will show that electrons can be made to move in a metal (or other) conductor when it is moved toward or away from an electric field, or when the electric field is moved toward or away from the conductor.

Materials needed:

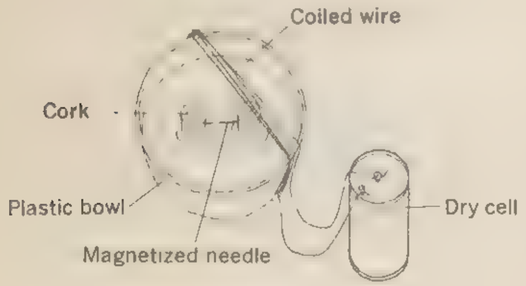
Plastic bowl filled with water
Iron or steel needle
Dry-cell battery
Bar magnet
2 small corks
Bell wire (insulated), 6 to 8 feet long

INTRODUCTION: Show the electroscope made in Activity 55 to the children. Review with them the facts that electrons pass from one object to another and cause an electrical charge to be apparent. Ask them how we knew when electrons were flowing through the electroscope into the leaves. Ask the

children, "Can you suggest a way for us to 'see' the electrons move?" Tell them that there is a simple device that will detect the flow of electrons. The device is called a galvanometer.

Commercial galvanometers, such as those used in a physics laboratory, are expensive and delicate instruments. For this reason it might be difficult to borrow one for use in the elementary school. In addition, the children will learn more about the principle on which a galvanometer operates and why it works the way it does if they make their own homemade device. This can be done in the following manner.

Have a child magnetize an iron or steel needle by stroking it (as in Activity 51) with a bar magnet. Then have him imbed each end of the needle into a small piece of cork and float the resulting indicator in the approximate center of the plastic bowl filled with water. (You may want to have one of the corks painted, using nail polish or some other non-water-soluble material, so as to be able to distinguish more easily between the two ends of the needle.) Take the insulation off both ends of the insulated wire and have a child coil it in a narrow band around the bowl, from top to bottom, as in the illustration. Make sure



that the wire is coiled around the bowl directly above the needle and in a direction parallel to that in which the needle has come to rest. If the wire is not parallel to the needle, rotate the bowl and coil slowly. The needle will alter its position until it is parallel to, and beneath, the wire.

To test the "galvanometer" to make certain it will function properly, use a dry-cell battery to make electrons flow through a wire. Have a child simultaneously touch the two uninsulated ends of the wire to the two terminals of the dry cell, that is, one wire end to one terminal, the other wire end to the other terminal.

What happens to the galvanometer? *(The needle turns until it is at right angles to the coil of wire.)* Have the child remove the wires from the terminals. What happens? *(The needle returns to its original position.)* Be careful not to leave both ends of the wire touching the battery for more than a few minutes, for to do so would ruin the battery.

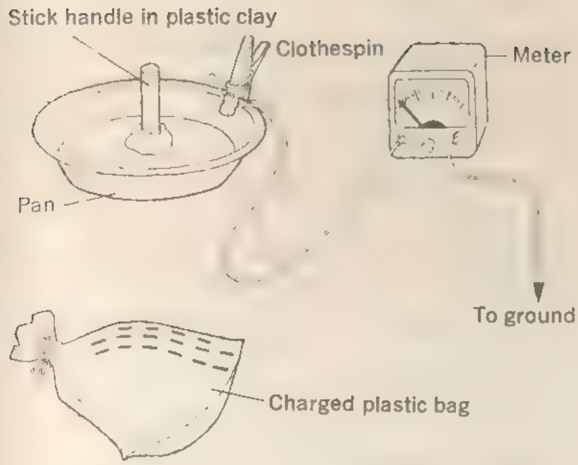
See what happens when the child touches the ends of the wire to the battery terminals, removes them, touches them to the terminals, removes them, and so on, several times. *(The needle will move in short spurts.)* What will happen if the ends of the wire are reversed before being touched to the battery terminals, that is, if each wire end is placed on the terminal opposite the one originally touched by that wire end? *(The needle will turn in the opposite direction, for the electrons are flowing through the wire in the opposite direction.)* Try it.

Having made their galvanometer and having observed how it works and what it can do, the children are now ready to use it to "see" that electric fields can make electrons move. For this part of the Activity they will need the following additional materials:

Materials needed:

- Homemade galvanometer or commercial galvanometer, d.c. milliammeter, or d.c. microammeter (may be borrowed from the physics teacher or from a TV-radio repairman)
- Bell wire (insulated), at least 6 feet long
- Plastic clay
- Shallow pan, 10 inch diameter
- Spring clothespin
- Wooden stick

Have the children attach two bare-ended wires, as long as needed, to a galvanometer. If the galvanometer made in this Activity is used, the bare ends of the wire coil should be used in the following steps in place of wires attached to the commercial galvanometer. They may use a clothespin to clip an end of one of the wires to a large, shallow pan as in the illustration. A stick or crayon set in a piece of plastic clay in the middle of the pan makes a good insulating handle so that electric charges on the pan will not be grounded to the hand. Attach the end of the other wire to a ground, that is, to a water faucet or another child's hand. Then rub an inflated plastic bag briskly with wool and watch the meter needle (or needle in the water) as the pan is



brought close to the bag and again as it is removed quickly. Have children observe the needle while moving the bag to and from the pan. What happens to the needle? *(When the needle moves, it indicates the electrons are moving in the wires and through the meter. When the needle moves to the other side of zero—or to the other side of the coil in the homemade device—it indicates that electrons are moving through the meter in the opposite direction. In some commercial meters the needle can move in only one direction, but you may notice it "trying" to go the other way when the pan or bag is moved.)*

Again encourage the children to raise questions and suggest ways to test their answers. Will the needle move if there is no wire connected to a ground? Why? *(Not usually, because an easy conducting path to the huge reservoir of charges is needed to allow a great enough flow of electrons to move the meter needle. Since the wire is not grounded, there is little or no place for the electrons to flow.)*

Learnings: (y,z) Electrons can be made to move in a conductor when it is moved toward or away from an electric field, or when the electric field is moved toward or away from it. (y,z) The ground and other large conducting bodies are huge reservoirs of charges that may readily admit and donate electrons. (y) A wire or other conducting path is needed to allow electron flow from an object to the ground and from the ground to an object.

Summing Up Ideas: Free electrons can be transferred from one body to another to produce electrically charged bodies. A body that has an electric charge is surrounded by an electric field. Changes in the relative positions of charged objects cause changes in their electric fields. Electrons may be caused to move through conductors by electric fields.

HOW DO MAGNETIC AND ELECTRIC FIELDS AFFECT EACH OTHER?

Up to now, we have suggested experiences to help children build concepts of the independent properties of electric fields and magnetic fields. Now we must extend their experiences to build the following concepts:

- Electric fields, when moving, produce magnetic fields.
- Magnetic fields, when moving, may cause electrically charged objects to move.

These interdependent fields are fundamental to the transmission of energy as electromagnetic waves. High-frequency motions of electric charges produce variations or waves in both electric and magnetic fields that may be transmitted through the combined electromagnetic field. The energy of electromagnetic waves can be converted into usable motion of electrons as in a radio receiver, in the temperature sensors of the body, or in the retina of the eye.

ACTIVITY 59 (y,z)

COMPARING MAGNETIC AND ELECTRIC FIELDS

Purpose: To show the similarities and differences of magnetic and electric fields

Concept to be developed: Magnetic and electric fields are not the same.

Materials needed:

3 magnets (including one large enough to lift a 1-pound weight)
Materials to test: brass keys and fasteners, copper coins and wire, silver coins and rings, iron or steel nails, paper clips, coat hangers, large needles and articles of paper, plastic, wood, leather
Pith ball or puffed cereal suspended with thread
Fur or wool
Hard-rubber rod
Balloon
2 large steel needles or hacksaw blades

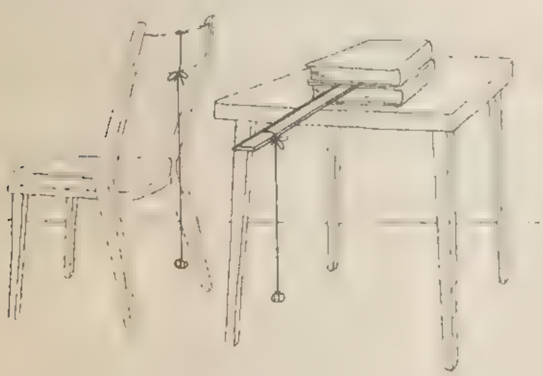
INTRODUCTION: Tell the children that now that they have studied electric and magnetic fields separately, they are ready to see in what ways the two are alike or different. You may lead children to raise these three very significant questions to answer in comparing electric and magnetic fields:

What materials are attracted in magnetic and in electric fields?

Are both magnetized and unmagnetized objects attracted in the electric field of a charged object?

Are both magnetized and unmagnetized objects attracted by the magnetic field around a magnet's pole?

Tell the children that they will have the opportunity to test objects to find answers to these questions. The best way to test an object for its reaction is to suspend it so that it will offer less resistance to attraction. Help the children devise a way to suspend objects to be tested so that they can move very freely. Many objects that cannot be picked up by a weak magnet or by a small charge will be moved by it when they are suspended by a thread from a yardstick or from a chair back, as shown in the illustration. Be careful not to use iron or steel objects within several feet of the objects being tested.



To answer the question about kinds of materials attracted by magnets and by charged objects, many small objects of various materials can be suspended in turn. Let children test each object by bringing to it, first, a magnet with strong field and, then, a charged object with strong electric field, such as a balloon rubbed with wool.

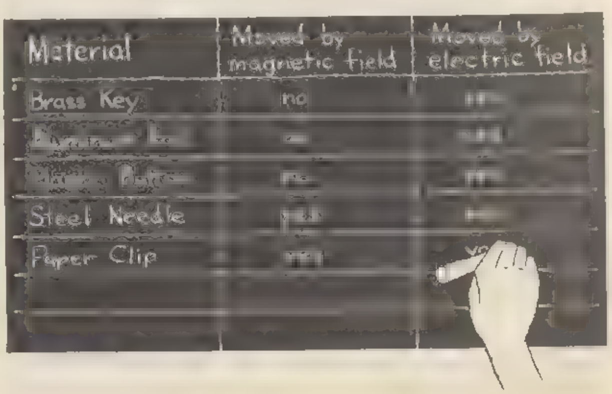
Have the children record their results after deciding on an orderly, usable way to do this. One way they can record their findings is shown in the accompanying table.

The children may be surprised to discover that all objects are attracted in electric fields. If the object is light and the charged object is placed very near, the movement is easily seen. However, in magnetic fields only certain kinds of materials are attracted: iron (steel is iron with tiny amounts of other elements added), nickel, and cobalt. However, nickel and cobalt objects are very uncommon and none may be available for testing. (The U.S. nickel coin has only 25% nickel and thus is not attracted.)

To test their answers to the other two questions, the children will need two objects alike except that one must be a magnet and the other not. Help them obtain two large steel needles (or hacksaw blades) and test each, to be sure it is not magnetized, by bringing it near a suspended paper clip. Is the paper clip attracted? *(There should be no attraction unless the needle or the paper clip is magnetized.)* Then magnetize *one* of the needles strongly by stroking it twenty times in the *same* direction with *one* of the poles of your strongest magnet. Leave the other needle unmagnetized. Test them again.

Now suspend each needle in turn and bring the charged rod near. What happens to each needle? Is it attracted? *(The children should see each end of each needle equally attracted in the electric field of the charged object.)* Then bring one pole of a strong magnet near each needle. What happens to the unmagnetized needle? *(Both ends of the unmagnetized needle are attracted.)* What happens to the magnetized needle? *(Only one end of the magnetized needle is attracted; the other end is repelled.)*

You may extend this activity by following the children's suggestions for other tests comparing magnetic- and electric-field effects. Then raise the question "Do you think we have enough evidence to say that magnetic fields and electric fields are *not* the same things?" *(Scientists are quite sure that they are not the same.)* We will see, in succeeding Activities, that though electric fields and magnetic fields are quite different, they may affect each other when they move rapidly.



Learnings: (x) Only magnetic materials are attracted in magnetic fields. All materials are attracted in electric fields. (y) *Unmagnetized* needles or hacksaw blades are attracted equally at each end in magnetic fields. Each end is also attracted equally in electric fields. (y) *Magnetized* needles or hacksaw blades are attracted equally at each end in electric fields. In magnetic fields, however, one end is attracted and the other is repelled. (x,y) Electric and magnetic fields are *not* the same.

ACTIVITY 60 (y)

"SEEING" MAGNETIC FIELDS MADE BY MOVING ELECTRONS

Purpose: To demonstrate that a magnetic field can be produced around moving electrons in a wire

Concept to be developed: A magnetic field is produced around a wire when electrons flow through it.

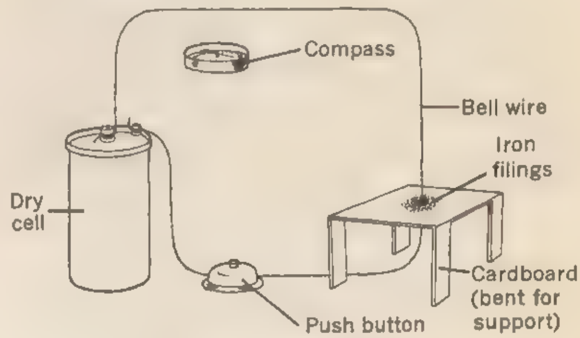
Materials needed:

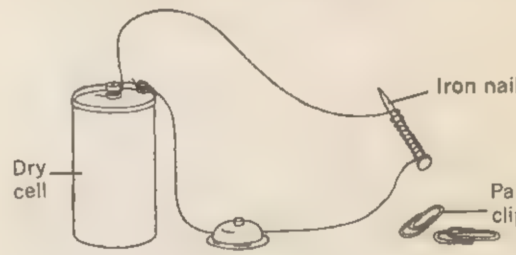
Dry-cell battery
Push-button switch
Compass, Boy Scout or miniature
Insulated bell wire, 6 feet long
Large nail
Paper clips
Iron filings, 1/4 pound

INTRODUCTION: Review with the children the fact that when the wire is attached to a dry-cell battery, electrons move through the wire. Tell the children that the constantly moving electric charges in the wire create a magnetic field around it. In this way the two fields help each other to transmit energy. Here are some ways children can discover that magnetic fields are generated around wires whenever electrons flow in the wires.

Arrange the materials as shown in the illustration. The cardboard may be supported on several books. Have a child sprinkle iron filings on the cardboard, push the button, and tap the board lightly. Children should then see the circular pattern made by the magnetic field around the wire. They should see the compass needle change direction as the compass is moved around the wire on the cardboard.

Have another child wrap several layers of coils of wire around a nail as in the illustration. This is a simple electromagnet. Use paper clips to see how strong a magnet it is. How many paper clips can be lifted at each pole of the electromagnet? Is there a magnetic field or an electric field at each pole? *(Magnetic field.)* How do you know? (Encourage the children to test this electromagnet's field to see if the same materials attracted by other magnets are attracted by it.)





Learnings: (y) A magnetic field is produced around a wire when electrons flow through it. (x) An electromagnet is made by winding wire about an iron core. It has strong magnetic fields around its poles when electrons flow in the wire.

ACTIVITY 61 (y,z)

MAKING ELECTRONS FLOW BY MOVING MAGNETS

Purpose: To show that moving a magnetic field across a conductor will produce an electron flow in the conductor

Concept to be developed: Just as electrons moving through a wire produce a magnetic field around the wire, a magnetic field moving across a wire will cause electrons to flow in the wire.

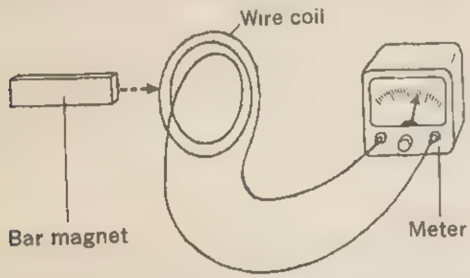
Materials needed:

Homemade or commercial galvanometer, d.c. milliammeter, or d.c. microammeter
Strong magnet
Insulated bell wire, 6 feet long
2 radio speakers, 4-inch diameter, permanent-magnet type (optional)

INTRODUCTION: Tell the children the story of the English scientist Michael Faraday (1791–1867). Faraday knew that electrons flowing through a wire caused a magnetic field to appear around the wire, and from this he deduced that by placing a magnetic field around a wire he could induce electrons to flow. Faraday experimented unsuccessfully for many years until one day he accidently dropped a magnet into a coil of wire and saw a movement of the needle in the meter to which the coil was attached. It was in this way that Faraday discovered the

basic principle of electromagnetic induction, that is, the principle of causing electrons to move in a wire by moving a magnetic field across it.

Form a coil large enough to pass easily over the pole of a strong magnet with about 15 turns of bell wire. You may find that two or three fingers will serve as a form that is about the right size. Connect the wires as shown in the drawing.



(If the galvanometer constructed in Activity 58 is used, the ends of the two coils should be joined to one another.) Children should observe the meter needle as the pole of the magnet is moved into the coil. What happens to the needle? *(It moves.)* Then observe what happens to the needle as the magnet is removed. *(It moves in the opposite direction.)*

Some questions that your children may like to explore on their own are these:

• Do electrons move through the coil when the magnet is stationary? when the coil is moved over the magnet?

• Do more electrons move when there are more turns of wire in the coil? when the motion is faster?

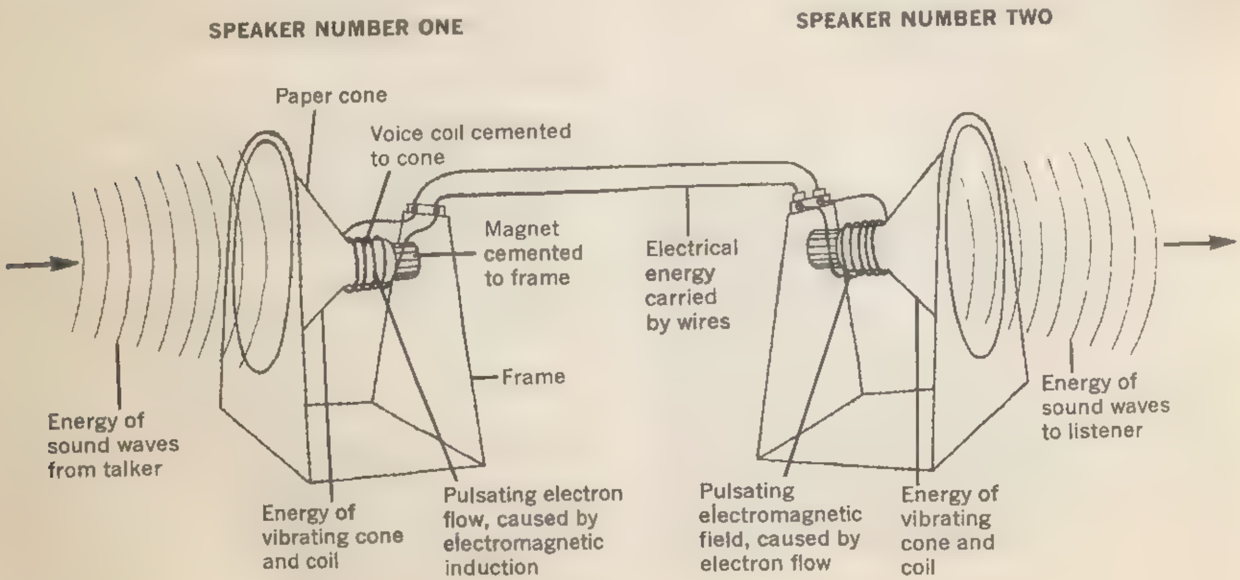
• Could you make a small generator that would produce an alternating flow of electrons in a wire?

The process by which electrons are made to move in a wire whenever there are variations in the magnetic field about the wire is called electromagnetic induction.

Most telephones use electromagnetic induction and electromagnetic field forces in a simple exchange of energy forms. In the simplified diagram below, a sound-powered phone system using two permanent-magnet-type speakers (no batteries) is shown.

Each speaker has a sturdy frame supporting the permanent magnet and the paper cone. The paper cone is cemented to the voice coil, which is free to vibrate in the field around the stationary magnet.

Have one of the children make a large drawing of the phone system on chart paper or on the blackboard. In a class discussion bring out the role of electromagnetic induction in the changes of energy from the talker to the listener. When the voice coil vibrates in the field around the magnet, what happens to the electrons in the voice coil? *(They move by electromagnetic induction, back and forth as the coil vibrates.)* How is the pulsating magnetic field caused at the listener's speaker? *(The pulsating, back and forth, electron flow from the No. 1 voice coil causes a pulsating electromagnetic field in the No. 2 voice coil.)* What causes the listener's cone to vibrate? *(Interaction of the fields of the*



No. 2 voice coil and the magnet.) Will the phone work in the other direction? *(Yes.)*

If you can obtain two speakers (those from discarded radios may work) have the children try 10-foot lengths of wire between speakers for first trials. The distance may be increased if the sound is loud and clear. The children should listen with their ears very close to the speaker. Very little energy is being used and much escapes in other forms and directions. Instead of speaking, the children may try a musical instrument, or tuning fork, or just scratching very close to or even touching the talker's speaker.

You may wish to extend the children's experiences with electromagnetic induction. The children may find readings in the library about electric generators and power plants where electron flow is produced by electromagnetic induction.

Help the children see that in electromagnetic induction, again, energy is conserved: the energy of moving coils, or magnets can be converted to the energy of moving electrons as in electric generators, sound-powered phones, etc.

Learning: (y,z) Electrons tend to move in a conductor whenever the conductor moves across a magnetic field or whenever a magnetic field moves across the conductor, that is, whenever there are variations in the magnetic field about the conductor.

ACTIVITY 62 (y,z)

SEEING THE EFFECT OF A MAGNETIC FIELD ON A MOVING ELECTRIC CHARGE

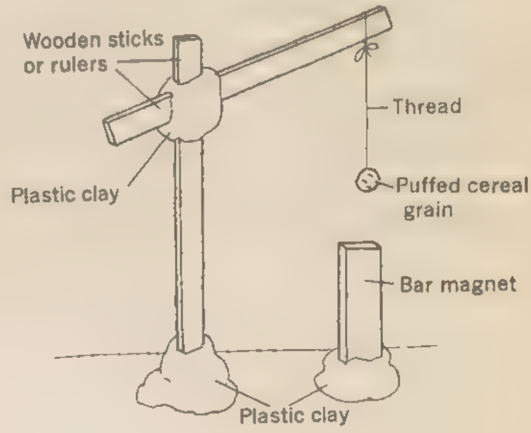
Purpose: To show the effect of a stationary magnetic field on a moving electric charge

Concept to be developed: A magnetic field is generated around an electrically charged body as it moves.

Materials needed:

Sticks
Thread
Bar magnet
Puffed cereal grains
Hard-rubber rod
Aluminum foil
Plastic clay
Wool or fur

INTRODUCTION: Ask the children, "What did we see happen when magnetic fields touched each other? Do you think you would be able to recognize magnetic fields by the way they affect one another?" Encourage the children to recall their experiences with earlier Activities that demonstrated the effects of interacting magnetic fields. Try to have them establish what they should look for in deciding whether or not magnetic fields are interacting.

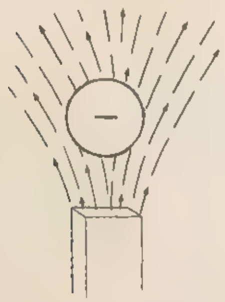


Have the children suspend a cereal grain free to swing over one pole of a strong magnet as in the drawing. Charge the hard rubber rod by rubbing it briskly with the wool. Transfer some charge to the cereal grain by touching it with the rod. Can the children observe any change in the way the ball hangs after being charged? *(There should be no change.)*

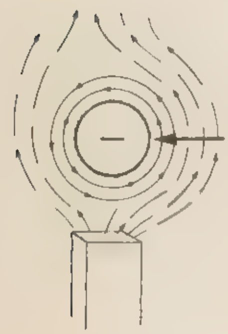
Have a child discharge or neutralize the ball by holding it in his hand. Then lift the ball to one side of the magnet and release it so it swings above the magnet's pole, very close to the pole but not quite touching it. A ball of rolled-up aluminum foil may swing longer if it is made heavier than the cereal grain (or a bead may be added to the cereal grain to make it heavier). Ask the children to describe how it swings. *(They should see that it swings steadily in the same direction.)* Next, charge the cereal grain again and, being careful not to neutralize it, lift it to one side as before and release it to swing. Perhaps it can be lifted with a glass rod or stick or loop of thread to avoid discharging it. What happens to the charged grain? Does it swing as steadily in the same direction as before charging? *(If the magnet has a strong field and the grain is highly charged, the grain should be deflected to the right in one direction of swing and to the left in the other. The direction of swing will change steadily.)*

Help the children interpret their observations in these terms: the grain seems to have a magnetic field only when it is charged and moving;

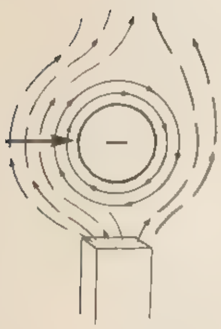
this field causes the magnet's field to push it sideways. In physics books you will find the diagram below, which compares magnetic fields to streams having direction as shown by the arrows. In this analogy a charged object in motion acts as if it had a circular magnetic field that reverses direction when the swing direction reverses.



Stationary charged ball in a magnetic field is not pushed in either direction.



Charged ball moving into the plane of the page through a magnetic field generates a counterclockwise magnetic field around itself and is deflected to the left.



Charged ball moving out of the plane of the page through a magnetic field generates a clockwise magnetic field around itself and is deflected to the right.

Learnings: (y) A charged cereal grain, standing still, *is not* pushed sideways by a magnetic field, standing still. (y) An uncharged cereal grain *is not* pushed sideways as it swings above a magnet's pole. (y) A charged cereal grain swinging above a magnet's pole *is* pushed sideways. (z) The push is due to the interaction between a circular magnetic field around the moving electric charge and the field about the magnet's pole.

Space exploration has met problems resulting from electric and magnetic field interactions. Charged particles radiated by the Sun, especially during times of increased sun-spot activity, are turned as they approach the Earth through its surrounding magnetic field. Instead of continuing straight into the surface, the charged particles are turned and tend to circle the Earth in regions called radiation belts. Particles escaping from the belts and those charged particles approaching the Earth near the poles are turned in directions that allow them to spiral into the Earth's atmosphere near the poles. The aurora borealis and aurora australis are produced by these particles. Of course, radiated particles and belts also pose problems in radio communication in space and on the Earth.*

Careful, critical thinking by the children is a goal of Activities such as the preceding, but more than the manipulation of materials is needed to attain it. Usually there must be a question that arouses the child's curiosity, one that lends itself to investigation at their level.

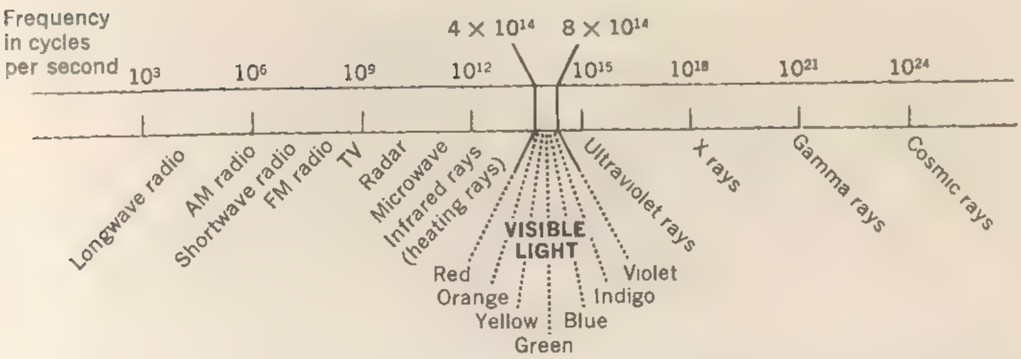
Summing Up Ideas: Electric and magnetic fields are not the same. When electrons flow through a wire, a magnetic field is produced in the wire; when a wire is moved through a magnetic field, electrons are induced to flow in the wire. An electromagnet is formed when electrons flow through a wire that is wrapped around a soft iron core, for a magnetic field is induced in the core. When a charged body moves through a magnetic field, it is deflected, for a magnetic field is produced around it that interacts with the magnetic field through which it is passing.

HOW CAN WE MAKE ELECTROMAGNETIC WAVES?

Scientists call the combined interacting electric and magnetic fields "electromagnetic field." The electromagnetic field seems to extend through all space and varies with any change of magnetic or electric fields and field sources. When a charged body is moved very rapidly, thousands or millions of times per second, electromagnetic waves may be produced that travel outward through the electromagnetic field at the speed of light, approximately 186,300 miles per second. These

* You can read more about radiation belts in *Space*, by Arthur Costa (Investigating Science with Children Series; Darien, Conn., Teachers Publishing Corporation, 1964).

THE ELECTROMAGNETIC SPECTRUM



electromagnetic waves are a wave form of energy. Electromagnetic waves can be detected when they cause electrons to move in a receiver at some distance from the source. As with other waves, electromagnetic waves are described in terms of frequency, wavelength, amplitude, and velocity.

Home radios that receive the AM Broadcast Band are sensitive to electromagnetic waves of frequencies from 535,000 to 1,605,000 cycles per second. The retina of the eye is sensitive to higher-frequency waves called light.

ACTIVITY 63 (y,z)

MAKING ELECTROMAGNETIC WAVES WITH A FILE

Purpose: To show how electromagnetic waves can be produced

Concept to be developed: Radio waves are a form of electromagnetic radiation.

Materials needed:

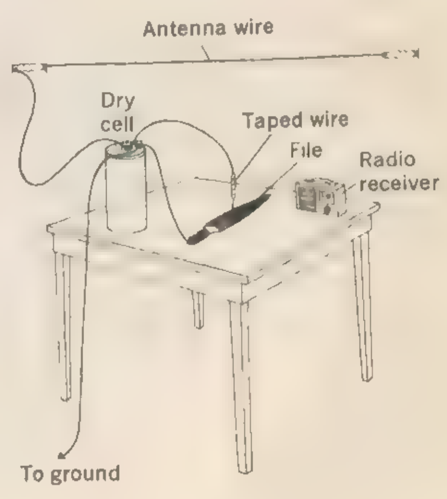
- Radio (pocket-type is adequate)
- Coarse file (any length)
- Bare or insulated wire, 20 to 50 feet long
- Electrical tape, cloth or plastic
- Dry-cell battery

INTRODUCTION: Tune the radio to receive a local broadcasting station and allow the children to listen to it for a few moments. Ask the children, "How does the music travel from the broadcasting station to our radio?" Encourage the children to give their theories. If some mention having heard of radio waves, tell them that scientists have discovered that radio waves are moving through the interacting electric and magnetic fields that seem to extend through all space. These waves are more accurately called electromagnetic waves. They are sent out into the air by a transmitter at the broadcasting station, and they are received by our radio because it has been made sensitive to the particular kind (frequency) of wave being sent. Tell the children it is possible to make some electromagnetic (radio) waves to see how they work.

A group of three or four children can set up the materials as shown in the illustration. The antenna is a wire stretched across the room, high enough to walk under. It can be either bare or insulated. One end should extend down to a table where the children may work. The supports for the antenna can be two nails or other projections, but the antenna must not touch any large metal object, pipe, or other grounding object. If a bare wire is used, tape can be used to insulate the antenna where it may touch some metal.

The children can make the ground connection by scraping or sandpapering about 1 foot of one end of a wire and winding it around a clean, bare water faucet or pipe. Use some tape to hold the bare wire in contact with the bare pipe. Bring the other end of the wire to the table near the antenna wire.

Two wires, *A* and *B*, each about 2 feet long (if insulated wire is used, bare an inch or two at each end), are attached to the dry cell as shown. Have a child attach one of these to the file by winding the bare end around the bare metal of the handle. A child can wind tape near the end



of the other wire so it can be handled without grounding charges to the hand.

To make some electromagnetic (radio) waves, have a child hold wire *A* where it is taped and slide it lightly along the file. Notice that it makes sparks. Radio-frequency vibrations of electrons of the atoms in the spark area cause similar vibrations of electrons of the antenna and ground wires, which in turn make radio waves in the electromagnetic field.

Have the children turn on the radio and tune it to a place on the dial where no station is heard, with the volume turned high. Then slide the wire along the file. A scratchy sound should be heard emanating from the radio if it is placed close to the file or to the antenna.

Some questions the children may investigate are these: Is lightning a spark? *(Yes.)* Does it cause radio waves? *(Yes, they are heard as a kind of static.)* How far from the antenna and file will the radio receiver detect radio waves? 5 feet? 10 feet? 20 feet? in the next room? *(The distance varies with the power of the radio.)* Are all radio receivers equally sensitive? *(No.)* Let them try another one and compare the distances from antenna and file to radios.

The children can send code messages with the file radio-wave maker. Have them practice making long and short scratches with the wire on the file in order to form the characters of the International code:

A ._	H	O ___	U .._
B _...	I ..	P .__ .	V ..._
C _._.	J .___	Q __._	W .__
D _..	K _._	R ._.	X _.._
E .	L ._..	S ...	Y _.__
F .._.	M __	T _	Z _. ..
G __.	N _.		

The children will find it helpful to practice saying the sounds: A is dit dah, B is dah dit dit dit, and so on.

Learning: (y,z) Radio waves are a form of electromagnetic waves.

ACTIVITY 64 (y,z)

MAKING ELECTROMAGNETIC WAVES WITH A DOORBELL

Purpose: To show another method of generating electromagnetic waves

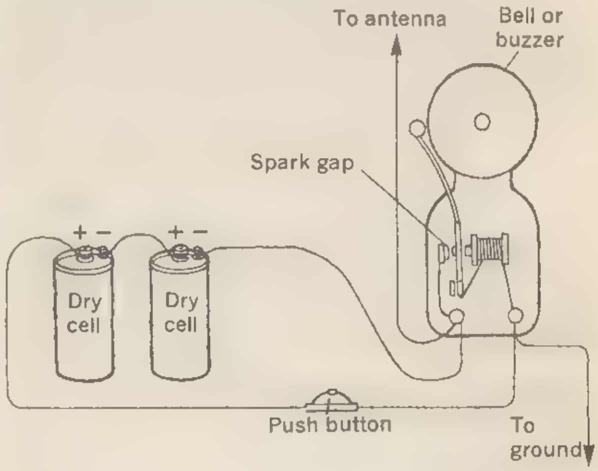
Concept to be developed: Electromagnetic waves can be radiated by swiftly moving electrons.

Materials needed:

Radio (pocket-type is adequate)
Bare or insulated wire, 10 to 20 feet long
Electrical tape, plastic or cloth
2 dry-cell batteries
Doorbell or buzzer
Coarse file

INTRODUCTION: Rub the file with a piece of wire, as in the preceding Activity, to generate sparks. Discuss this method of generating electromagnetic waves with the children to establish firmly in their minds the concept that it was the spark (caused by swiftly moving electrons) from which the electromagnetic waves were radiated. Ask the children, "Could we create electromagnetic waves of higher amplitude by increasing the size of the spark?"

To make some stronger (higher amplitude) electromagnetic waves, have the children set up the materials as shown below.



When the bell is ringing children may see the spark at the make-and-break point of the bell. As with the file, the children should connect the antenna and ground wires on each side of this spark. At the spark, electrons are vibrating and producing radio-frequency electron vibrations in the antenna, in the ground, and in the electromagnetic fields which surround the radio receiver.

The coils in the bell help make these radio waves stronger by storing some energy in their magnetic fields. Through electromagnetic induction, this stored energy produces a strong electrical energy surge at the spark.

In these Activities, encourage the children to suggest things they want to try, to plan carefully and test them whenever possible. You may suggest some things to try by asking the following:

- Do you think a coil of many turns of bell

wire wound on a nail attached to the slide wire (Activity 63) would make it broadcast farther?

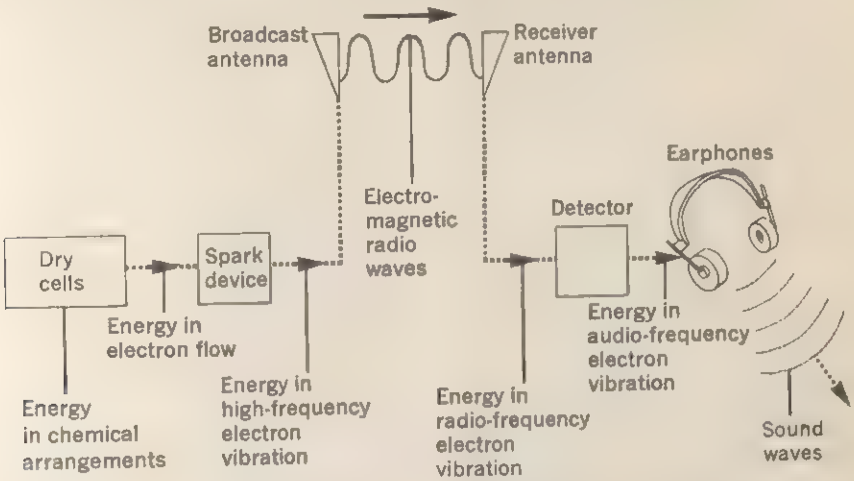
• How does increasing the number of dry cells affect the energy of radio waves produced by either or both of the broadcasters?

• How can we compare their energies?

• Does a shorter antenna broadcast as far as a longer or a circular or a rectangular one?

• Do radio waves go equally far in every direction from the antenna?

Summing Up Ideas: Electromagnetic waves are produced in electric sparks (including lightning). Electrons in the spark, antenna, and ground, vibrating at radio frequencies, cause variations in the electromagnetic field (radio waves). Radio waves are a form of energy that is converted from the energy of some electrical source (such as a dry cell.) They may be reconverted to energy of electron movement and then to sound waves in a radio receiver.



IMPORTANT IDEAS IN THIS CHAPTER

For the kindergarten, primary, and intermediate grade children, the kinds of ideas with the most meaning and application are these:

• Magnetic fields are located around magnetic poles.

• Electric fields are located around electric charges.

• Magnetic fields always extend between the two poles of the magnet.

• Magnetic fields readily penetrate all materials except iron, steel, nickel, and cobalt.

• Some objects become electrically charged when rubbed with fur, wool, or silk.

• Like charges repel each other; unlike charges attract each other.

• A neutral (uncharged) object is attracted by the electric field of a charged object.

• Electric fields, when moving, produce magnetic fields.

• Magnetic fields, when moving, may cause electrically charged objects to move.

• Electric and magnetic fields are not the same.

• Electromagnetic waves are produced in electric sparks.

In the intermediate and upper grades, these concepts should be expanded to include the following:

• Moving one magnet close to another causes changes in their magnetic field patterns and strengths.

• Magnetic fields can be induced in iron and steel objects.

• Changes in the relative positions of electrically charged objects cause changes in their electric fields.

• Electrons can be caused to move through metals or other conductors by electric fields.

• A magnetic field is produced around a wire when electrons flow through it.

• Electrons tend to move in a conductor whenever the conductor moves through a magnetic field or whenever a magnetic field is moved across a conductor.

In addition this chapter continues to develop the principle of conservation of energy. For example, electromagnetic waves are converted from some kinds of energy and can be converted back into still other forms. Perhaps the diagram below will help your children think more clearly about electromagnetic radiation as a process in which energy is conserved.

5

INVESTIGATING HEAT AND LIGHT WAVES

That children have had experiences with heat and light is clearly indicated by the questions children ask:

"Is there a way to collect light on a sunny day to use sometime when it is dark?"

"Is it the light or the heat from the Sun that a magnifier can focus to a tiny spot?"

"How does the thermometer work?"

"How does heat from the furnace come to my room?"

"How does an electric eye make the door open?"

Some of the conventional answers to these questions simply restate the conditions under which the subject of the question occurs. For instance, if a child asks why it is possible to burn something with a magnifying glass and we answer that the glass focuses the Sun's rays on a small point, we are describing the conditions under which the burning occurs, but we are not explaining why it occurs. In the search for more comprehensive answers, scientists have derived a theory that links very closely the forms of energy that are called heat and light: it is called the electromagnetic wave theory.*

Heat and light energy are carried by electromagnetic waves. As can be readily seen from the illustration on page 69, heat and light are related to radio waves, television waves, X rays, and cosmic rays, for they are all forms of electromagnetic radiation (that is, they are all a part of the electromagnetic spectrum). All of these forms are therefore closely related in nature, yet they seem very different to us because of the ways in which we sense or "receive" them.

* Not all of the properties of light can be explained by considering it as a wave form; therefore, to explain the other properties, scientists also speak of light traveling as *photons*, which are separate packets of energy. For a fuller discussion of this concept see *Physics*, Physical Science Study Committee (Boston, D. C. Heath and Company, 1960), Chap. 33.

From the illustration of the electromagnetic spectrum on page 69, it can be seen that the difference between electromagnetic waves that we call radio, heat, light, etc., is one of frequency. The frequency of light waves (400 million million to 800 million million waves per second) is higher than the frequency of infrared, or heating, waves (1 million million to 399 million million waves per second); infrared waves, in turn, have a higher frequency than radio waves, which cover the spectrum from the frequency of long radio waves (1,000 waves per second) to the frequency of microwaves (999 thousand million waves per second).

(It should be noted that it would be equally correct to say that the difference between the types of waves in the electromagnetic spectrum is one of wavelength. As we saw earlier, the frequency and the wavelength are related by the equation "Wavelength is equal to the distance traveled divided by the frequency"—$l = d \div f$, or $l = \frac{d}{f}$. The distance traveled by all forms of electromagnetic waves in any given time period is the same since the electromagnetic waves all travel at the same velocity—186,000 miles per second. The wavelength will therefore be inversely proportional to the frequency; that is, the greater the frequency of the waves, the shorter the wavelength. The electromagnetic radiation with the highest frequency, cosmic rays, has the shortest wavelength. The electromagnetic radiation with the lowest frequency, long radio waves, has the longest wavelength.)

Light waves are the kind of electromagnetic waves to which our eyes react so that we can see. Black is the sensation when no light waves enter the eye. White is the sensation when all frequencies of visible light enter the eye at the same time. Actually, there are other combinations (mixtures of frequencies) that will also produce the sensation of white.

The various colors of the visual spectrum—red, orange, yellow, green, blue, indigo, and violet—are the sensations when light of a specific frequency (within the range of frequencies that make up the visible light portion of the electromagnetic spectrum) reaches the eye. For example, when electromagnetic radiation of the frequency of 580 million million (which may be written 5.8×10^{14}) waves per second reaches our eyes, the sensation of green is produced. The following chart lists the frequencies and wavelengths associated with the colors of the visible spectrum:

Pure Color	*Frequency (in waves per second)*	*Wavelength (in centimeters)*
Red	4.6×10^{14}	6.5×10^{-5}
Orange	5.0×10^{14}	6.0×10^{-5}
Yellow	5.2×10^{14}	5.8×10^{-5}
Green	5.8×10^{14}	5.2×10^{-5}
Blue	6.4×10^{14}	4.7×10^{-5}
Indigo	6.8×10^{14}	4.4×10^{-5}
Violet	7.3×10^{14}	4.1×10^{-5}

Thus light that causes the sensation of blue-green when it reaches the eye has a frequency between 5.8×10^{14} waves per second (pure green) and 6.4×10^{14} waves per second (pure blue).

It is believed that the source of light waves is electron movement causing variations in the electromagnetic field. It is thought that in order to produce the millions of millions of waves per second associated with visible light, the electron movements occur inside atoms. Such "high" frequencies seem compatible with the small space for electron movement inside the atom.

Heat energy that radiates from a hot iron, one that is not glowing, consists largely of the infrared waves. Their frequencies are much higher than those of radio waves but lower than those of light waves. Their origin, as with light, is in the electron movements inside atoms. The other electromagnetic waves (radio, light, X ray, etc.) may also cause heating.

Besides reacting to light, the human body also reacts to infrared waves, or heat, to produce sensations of heat. However scientists do not have as clear a knowledge of the human temperature sensory organs as they do of the eye.

When heat energy, most commonly in the form of infrared waves, is absorbed by substances, it sets their molecules in motion. That is, the heat energy is converted into molecular motion. Thus, the temperature of a substance corresponds to the average motion of its molecules. The greater the average motion, the higher the temperature. The increased energy of the molecular motion in these substances affects the electrons in the atoms, causing them to produce infrared waves. Thus, a substance that has high temperature (that is, high molecular motion) radiates heat energy and feels warm.

Radio waves (as an example of electromagnetic waves that we cannot sense) are the relatively low-frequency waves produced by electron vibration in radio broadcasting circuits. We have no sense organ affected by radio-frequency waves; therefore, though they may constantly surround us, we are unaware of their existence. Radio and television receivers convert the radio-wave energy to sound waves and to light waves that we can sense. Through the Activities in this chapter you will see ways to guide children toward the interpretation of heat and light as forms of energy. Some of the concepts children may develop include the following:

- Thermometers measure temperature.
- Objects at the same temperature may possess different amounts of heat energy.
- Materials are different in their capacity to absorb heat, reflect heat, conduct heat and in their heat transparency.
- Most materials expand when heated.
- Heat energy can be used to make things move.
- Light waves travel in a straight line. They do not turn corners, and shadows appear behind objects because of this.
- All colors (wavelengths of visible light) are present in white light; rainbows occur because each color in a beam is bent differently in passing through water, glass, etc.
- Our eyes see the various amounts and colors of reflected light from objects.
- Mirrors can reflect light waves with little scattering and exactly at the angle predicted, such as in periscopes, range finders, etc.
- Light waves are bent when passing through a magnifying lens so that they form images, as in cameras, telescopes, etc.
- Light and heat energy can be converted directly to electric energy by such devices as

electric eyes, light meters, and thermocouples, and to chemical energy by green plants in the process of photosynthesis.

Certainly it is not expected that children will fully appreciate the myriad implications and applications of these principles. However, their experiences with electric and magnetic fields, light, and heat should be guided in the direction of these principles rather than left in undirected, fragmented patterns.

WHAT ARE SOME OF THE CHARACTERISTICS OF HEAT WAVES?

As an introduction to this chapter and to the subject of heat and light energy, it will be well to mention that the children will now discover that these are two kinds of electromagnetic waves, which cause heat and which are responsible for visible light. As with sound waves, or any other kinds of waves the children have studied so far, it is important to understand clearly what heat and light waves are like, and what effects they have on people and their environment. Therefore, a first consideration will be to find out all about the characteristics or properties of heat waves, and then to do the same with light waves.

A good way to find out what heat waves do is to observe and test their effects or behavior with various common materials the children can easily obtain. For example, children may have observed what happens when a bit of metal is heated, as when a nail is held by pliers in a flame. They know that it becomes very hot and that when it is brought near to a person's hand he can feel the heat energy coming from the nail. But do they know why, and what is taking place within the nail? The following Activities will help the children to discover the answer to these and other interesting questions about heat energy.

Before proceeding with the Activities on heat, however, the children should be presented with a careful definition of the terms *temperature* and *heat*. They are *not* the same.

Temperature is a measure of average molecular energy of motion of the individual molecules in a substance.

Heat is a measure of total molecular energy of motion of all the molecules in a substance.

For example, a cup and a tub of water at the same temperature have molecules of equal *average* energy. However, the tub of water would have much more total heat energy than the cup of water at the same temperature, for it has many more molecules and thus greater total energy. If a cup and a tub of water were each heated to the boiling point—212° Fahrenheit—the tub would retain its heat much longer because it has more heat energy in its greater volume of water.

ACTIVITY 65 (y)

SEEING THE DIFFERENCE BETWEEN TEMPERATURE AND HEAT

Purpose: To establish the idea that temperature and heat are not the same

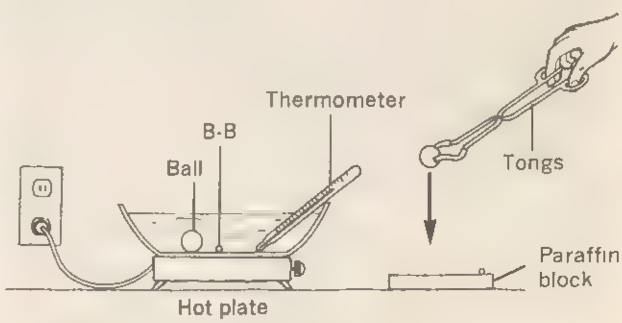
Concept to be developed: Temperature is a measure of the average molecular energy of motion of a substance; heat is a measure of the total molecular energy of motion of a substance.

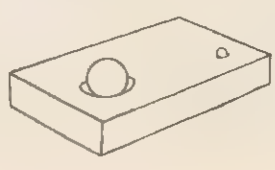
Materials needed:

Steel ball and steel BB or lead weight and lead BB
Hot plate
3 pans
Tongs (food lifting type is all right)
Paraffin block
Thermometer (all glass, red liquid or yellow backed)

INTRODUCTION: Tell children that before beginning their investigation into the characteristics of heat waves, they must learn to understand the difference between two very important words they will be using in many activities to come. The words are heat *and* temperature. *Encourage them to give their theories about what the difference is. Then ask them to see what conclusions they can draw from the following Activity.*

Have the children set up the materials listed above as shown in the illustration. Have them heat the ball and the BB in boiling water for five minutes. Place the thermometer in the water to measure the temperature.





What is the temperature of the water? *(The thermometer should read about 212° Fahrenheit or 100° centigrade.)* A child may ask, "What are the temperatures of the ball and the BB?" Even though it is difficult to measure the temperature of the ball or the BB, we would safely assume that they are the same temperature as the boiling water. Explain to the children that this is because energy of motion generated by the heat is transferred from the molecules of water to the molecules of the ball and the BB until all molecules have the same energy of motion.

Next, use the tongs to quickly move the ball and the BB from the boiling water to the paraffin block. What happens to the paraffin block? Why? *(The ball melts more paraffin because the ball contains more molecules than the BB and therefore more total energy of motion—or heat—to transfer to the paraffin molecules.)* What is happening to the temperatures of the ball and the BB? *(They drop until they are the same as the temperature of their surroundings.)** Which of the two objects will take the longer time to cool down to room temperature? Why?

Learnings: (x) Thermometers measure temperature. (y) Larger objects have more heat energy than small objects of the same material at the same temperature. (y,z) Larger objects transfer more heat to the surroundings than small objects of the same material as the temperature of each drops the same amount.

ACTIVITY 66 (y,z)

COMPARING THE HEAT TRANSPARENCY OF MATERIALS

Purpose: To show that all materials do not allow heat energy to pass through them in equal quantities

Concept to be developed: Materials differ in their transparency to heat energy.

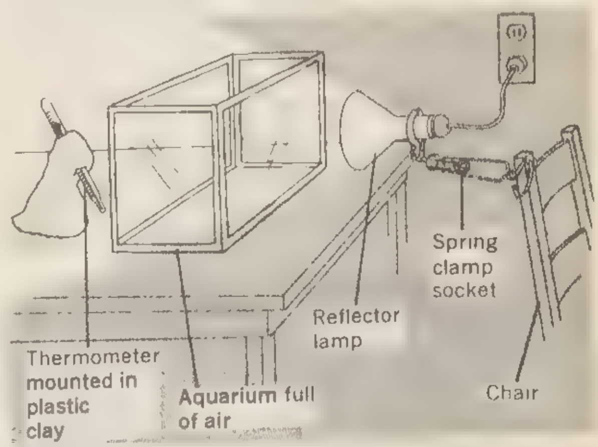
Materials needed:

Gooseneck lamp or spring-clamp socket reflector lamp (150-watt, indoor type)
Thermometer
Watch or clock (with a second hand)
Cellophane sheets (from art and crafts store): 6 clear, 6 red, and 6 blue
Glass squares, red and blue
Aluminum foil
Cardboard square
Clear plastic bag
Sheet-metal square
Aquarium
Waxed paper
Sheet of construction paper
Piece of cloth
Plastic clay

* For more information about the molecular nature of matter see *Atoms and Molecules*, by Seymour Trieger (Investigating Science with Children Series; Darien, Conn., Teachers Publishing Corporation, 1964).

INTRODUCTION: Ask the children to think of a winter day when they sat near a sunny window. What happened? Did they feel any heat? If so, why? If children say that the heat came through the glass, develop the idea of transparency by saying that the heat came through the glass just as light did. Therefore the glass is transparent to heat as well as to light. Tell children that this is one of the characteristics of heat energy—it will pass through transparent materials. Ask children what other materials they think will let heat pass through.

Have some children set up the lamp and thermometer about 12 inches apart. The first measurement will establish a standard, or control, for comparison with later measurements.



This standard will be the transparency of air, which will remain the same in all tests.

Turn on the lamp and have a child hold the watch and begin to count the seconds as soon as the thermometer liquid is a little above room temperature (75° or 80° Fahrenheit). Have him count carefully the number of seconds required for the liquid to rise 5° Fahrenheit.

Having set up the control, the children are now ready to test the heat transparency of the materials on the following list. Have the children insert various materials midway between the lamp and the thermometer. Exactly the same number of seconds must be used in each of the following tests. The distance from the lamp to the thermometer must not be changed. Then we

may assume that equal amounts of heat energy from the lamp are used in all tests. Between trials, enough time must be allowed for the thermometer to return to room temperature.

(A) Air only (controlled situation)

(B) An empty aquarium (two panes of glass and several inches of air between)

(C) An aquarium full of water (two panes of glass and several inches of water between)

(D) Cellophane:

1 clear sheet
6 clear sheets
1 red sheet
6 red sheets
1 blue sheet
6 blue sheets
3 red sheets and 3 blue sheets

(E) A pane of red glass

(F) A pane of blue glass

(G) One sheet of waxed paper

(H) Six sheets of waxed paper

(I) A clear plastic bag

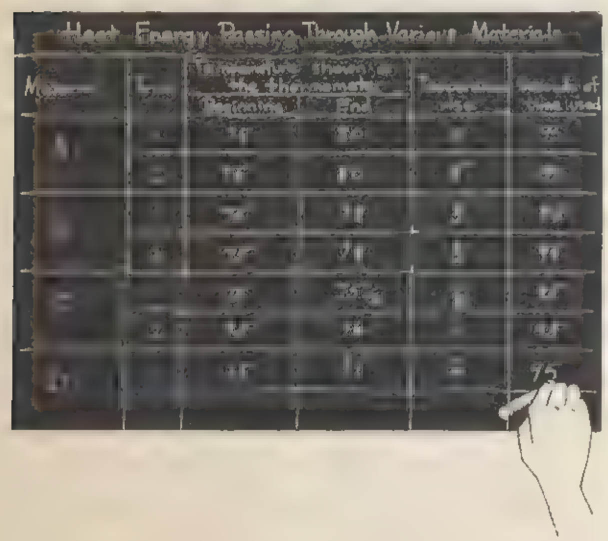
(J) A piece of sheet metal

(K) A sheet of aluminum foil

(L) A sheet of construction paper

(M) A piece of cloth

Your children may want to record the results of the Activity on a chart similar to this one:



Of course, the numbers on your chart may be quite different because your materials and surroundings differ from those in the example.

Lead the children to suggest ways to improve the Activity and to try out their ways. Ask them, "Do you think the thermometer would register changes more consistently if it were in a small box with the open side facing the source of heat?" *(Probably so, because the box would limit air currents and heat escape.)* Ask, "Do you think the thickness of a substance makes a difference in its transparency to heating energy?" *(Yes.)* "Are the substances that are very transparent to light also very transparent to heat?" *(Yes.)* "Do you think more than one trial in each situation was needed?" *(Yes, as a check on the results.)*

As the children make their statements of comparison and summary, guide them to use qualifying expressions such as "perhaps" and "I think" and to support their statements with reasons (from observations, readings, etc.). Younger children can experience heat transparency of substances in a nonquantitative way: have a child use his own hand in place of the thermometer and ask him to describe the heat sensation he feels as the heat energy comes through the various materials.

Learnings: (x) Materials differ in their heat transparency. (x) The thicker we make a substance, the less heat energy will pass through. (y,z) Careful planning and measuring are required to make quantitative comparisons.

ACTIVITY 67 (y,z)

TESTING MATERIAL FOR ABSORPTION OF HEAT ENERGY

Purpose: To show that all materials do not absorb heat energy in equal quantities

Concept to be developed: Color plays an important role in determining the quantity of heat energy absorbed by a substance.

Materials needed:

Gooseneck lamp or spring-clamp socket reflector lamp (150-watt, indoor type)
Thermometer
2-inch square of aluminum foil
Plastic clay
Construction paper (black, white, and various colors)
Watch or clock with a second hand

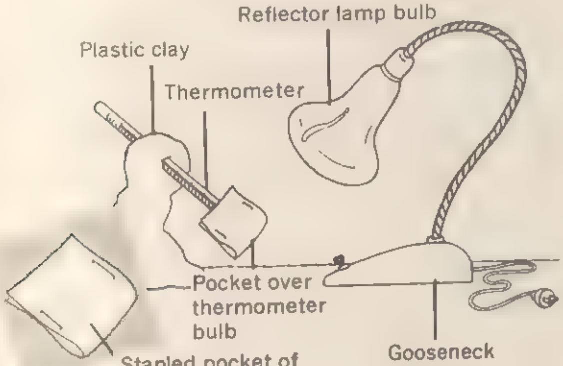
INTRODUCTION: Review with the children the fact that one of the tests in the last Activity showed that the thicker a heat transparent substance is, the less heat it allows to pass through. This was shown as they tested first one sheet of cellophane and then six sheets of cellophane. Raise the question "Since the amount of heat from the lamp was the same in all cases, where did the heat go?" Then introduce the idea that materials, in addition to allowing heat to pass through, may absorb some heat. Just as

materials differ in their ability to allow heat to pass through, so do they differ in their ability to absorb heat. This ability is also affected by their color.

Point out that a knowledge of the materials and the colors that absorb heat energy rapidly is very important to architects, clothing designers, furnace and air-conditioning designers, and others. Then lead the children to explore the question "Is heat energy absorbed equally by all colors?"

Have a child prepare 1- by 2-inch rectangles of each color of construction paper. Fold and staple each piece to make a 1-inch-square pocket. Have a child prepare a pocket of white construction paper covered with aluminum foil.

Children may start with the black paper pocket and use the results as a standard of comparison for the other test pockets. Arrange the materials as shown in the illustration. Turn on the lamp



and have a child hold the watch and begin to count the seconds as soon as the thermometer liquid rises a little above room temperature (75° or 80° Fahrenheit). The time to be used in all the other tests should be the number of seconds required for the liquid to rise 5° Fahrenheit in the control (black paper pocket) situation. Using the same time for each test insures equal amounts of heat energy from the lamp in each trial. These tests cannot be made hastily because enough time is needed for the thermometer to cool to room temperature between trials.

In the preceding Activity, the children discovered that construction paper is not very transparent to heat radiation. Therefore, in this Activity, we can assume that the rise of liquid in the thermometer is caused by the heat produced in the colored paper by the heat radiation it *absorbed*. We can also assume that the same fraction of the heat is transferred from the paper to the thermometer in each trial; this assumption is reasonable, since the materials used in each are the same except for color.

Help the children construct a form to record the data obtained, allowing two or more trials for each test. In comparing and summarizing, encourage the children to make clear statements of their ideas and observations, to consider ideas of others even when they do not agree, to cite readings and other evidence to support statements that are made, to suggest ways to test answers that are proposed—in essence, to think carefully and to keep an open mind.

For younger children, you may provide experiences similar to those above, but nonquantitative in nature. Have the reflector lamp shine down on a black sheet and a white sheet of paper, both lying side by side on a table top. After several minutes have a child touch the table top under each sheet of paper and tell which spot is warmer. Try other colors. Of course, concept development can be extended by using many other substances besides construction paper. Try cellophane, cloth, metal pans, etc.

Learnings: (x,y) Various colors differ in their absorption of heat energy. (y,z) Careful planning and measuring are required to make quantitative comparisons.

ACTIVITY 68 (y,z)

COMPARING MATERIALS THAT REFLECT HEAT ENERGY

Purpose: To show that all materials do not reflect heat energy equally well

Concept to be developed: Color plays an important part in determining the quantity of heat energy reflected by a surface.

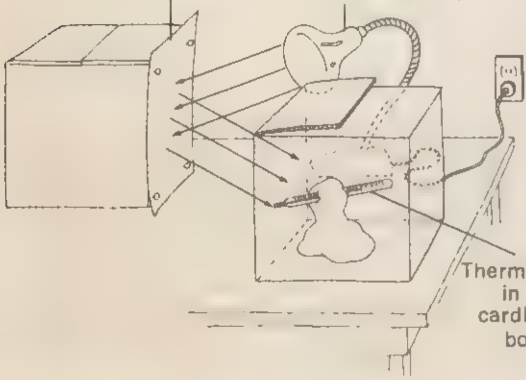
Materials needed:

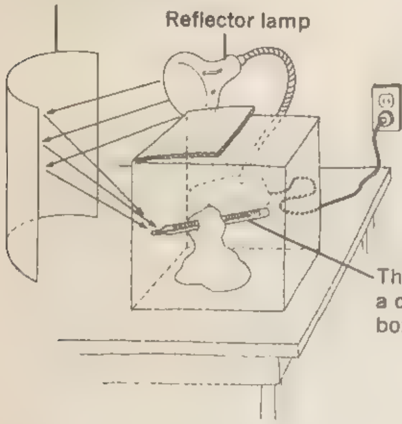
- Gooseneck lamp or spring-clamp socket reflector lamp (150-watt, indoor type)
- Thermometer (all glass, red liquid or yellow-backed)
- 2 cardboard boxes (about 10 inches square)
- Construction paper (white, black, and assorted colors, 8½ by 11 inches)
- Aluminum foil pasted to construction paper, 8½ by 11 inches
- Watch or clock with a second hand

INTRODUCTION: Review with children that in the last Activity they saw that black absorbed the most heat and that white absorbed the least. Yet the source of heat for both colors was the same. Pose the questions, "What happened to the heat that wasn't absorbed by the white color? Where did it go?"

Encourage the children to give answers and, if they are baffled, suggest that the following experience may give a clue to the answer they are looking for.

Ask a child to come to the front of the room and stand in front of the lamp. Turn the lamp on. Have him tell the other children whether he feels more heat when the reflector is turned toward him, away from him, or taken off the bulb completely. Ask the children, "What does a reflector do?"





Help the children arrange the materials as shown in the illustration. Encourage them to suggest ways to improve the arrangement. One improvement might be to bend the reflector so that it will focus the heat rays on the thermometer. In order to answer the questions above, it is important that only reflected heat energy reach the thermometer.

To compare the reflective capacity of the various colors, the children must select a standard to be used for comparison. White is the best standard, for it is a good reflector of heat.

As in Activities 65, 66, and 67, determine a number of seconds or minutes to be used in each test and observe the thermometer liquid rise for each reflector. (Of course, as a control, a trial should be made using no reflector.) Plan a chart similar to those made in Activities 66 and 67 so the children can record their findings. This record will be useful in subsequent discussions and for summarizing.

You will notice in these tests with reflected heat energy that light is reflected also. This reflected light may serve as a guide for the best position of the reflector in directing the heat energy toward the thermometer. Use this guide especially if you curve the reflector to concentrate the heat energy on the thermometer.

Children may wonder whether heat and light energy are the same thing, for in all of the preceding Activities the source of heat was also a source of light. The answer is that although *all* frequencies of electromagnetic radiation, including those we sense as visible light, can cause heating, infrared waves (which are invisible) are the principle cause. Thus, while it is true that light waves can cause heating, it would be incorrect to say that light energy is the same as heat energy.

To test this for the reflector lamp in the previous Activities, you can substitute some other source of heat energy—one that radiates little or no light, such as a very hot iron or a hot plate (on its side to face the target, of course). One reason for using the reflector lamp in our Activities is that children can see when it is in use and are less likely to be burned by accidentally touching it.

Younger children can engage in many non-quantitative activities related to the above experiences. They can share their experiences of the Sun's heat reflected from the sandy beach or from the water, or of a reflector used in Boy Scout cookery and in charcoal grilling. They can try reflecting the light and heat energy of the Sun with a large mirror, aluminum foil, or a white bed sheet; the reflected heat energy can be felt in this way.

Further study and reading about solar heating, solar furnaces, and solar energy for space scientists may be of interest to some of the children.

Learnings: (x,y) Various colors differ in their ability to reflect heat energy. (y,z) Curving the

reflector so it concentrates reflected light also concentrates the heat energy it reflects. (y,z) Quantitative comparisons require careful planning and measuring.

ACTIVITY 69 (x,y)

TESTING THE SPEED OF HEAT CONDUCTION IN DIFFERENT MATERIALS

Purpose: To show that heat energy travels more rapidly in some materials than in others

Concept to be developed: Heat is conducted more rapidly through some materials than through others.

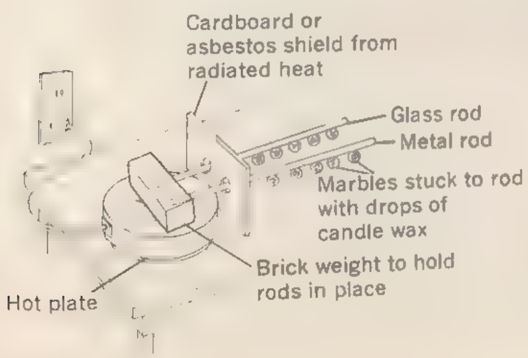
Materials needed:

- Hot plate
- Glass tube or rod and a metal rod (such as a curtain rod) Both rods must be of the same diameter.
- Candle
- Cardboard
- Marbles
- Brick
- Watch or clock with a second hand

INTRODUCTION: Point out to children that thus far in the study of materials and their reactions to heat energy they have seen how materials vary in ability to absorb, reflect, or allow heat energy to pass through. Now they will see that heat energy moves some materials, and that in some materials the heat moves faster than it does in others. This process is called conduction.

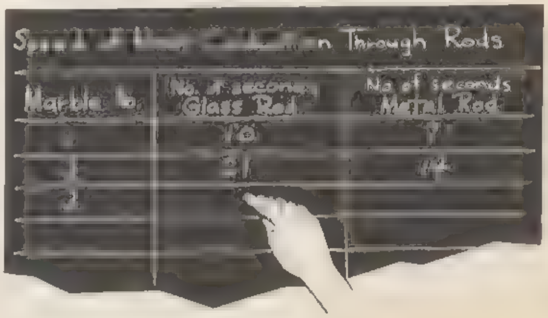
Ask children what examples they can think of to show that heat is conducted, or moves, in a solid material. What happens when they hold hot dogs over a fire with metal forks? Why do most forks used for outdoor cooking have wooden handles?

(In the *radiation* of infrared waves, heat energy is transferred at the speed of light, 186,000 miles per second. In the *conduction* of heat from molecule to molecule through solid materials, the speed may be very slow. Scientists believe that electromagnetic-wave radiation and collisions between molecules, as well as some electron movement, are involved in heat conduction.)



If you can obtain different materials of similar sizes and shapes, you can set up a controlled experiment to determine relative speeds of heat conduction. Attach marbles to both the glass and metal rods by melting candle wax onto the rod and sticking the marble into the wax puddle; when the wax solidifies, the marble should stick to the rod. Then have the children set up the glass and metal rods as shown in the illustration.

Use the brick to hold the rods against the hot plate as shown in the drawing. Use the square of cardboard as a shield to prevent the radiated heat from reaching the marbles. Turn on the hot plate and have a child record the number of seconds needed to melt the wax under each marble. A form like the one illustrated may be



used. You may guide the discussion of the children's findings by asking, "In which rod was the heat conducted faster? Will putting a large nail in a potato help it bake faster? Why?"

Learning: (x) Heat is conducted faster through some materials than through others. Through further discussion, testing, and sharing of experiences you may lead the children to generalize that metals conduct heat more rapidly than glass, wood, air, and many other materials that are poor heat conductors.

ACTIVITY 70 (y,z)

TESTING HEAT INSULATORS

Purpose: To show that some materials that are not good heat conductors may be used as insulators

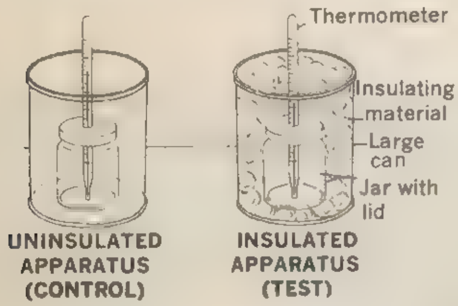
Concept to be developed: Insulators are materials that conduct heat energy slowly.

Materials needed:

- 2 large cans (quart or gallon size)
- Ice chest or hot-drink carrier
- 2 half-pint jars with lids
- 2 thermometers (all glass, red liquid or yellow-backed)
- Materials to test: steel wool, newspaper, cloth, sand

INTRODUCTION: Good heat conductors are needed for cooking utensils, auto radiators, etc. Poor heat conductors are called heat insulators and are used for insulating houses, submarines, space vehicles, hot-drink carriers, and clothing. Show a hot-drink carrier, such as a thermos bottle, to the children. Ask them, "Why does this keep things placed inside hot or cold?" Have children advance their theories. Encourage them to find out what is inside the thermos bottle (the lining) and suggest that they look up the meaning of the word insulate.

You can help the children compare the insulating qualities of various materials in the two insulation testers shown in the illustration.



To test the insulation quality of a material, have a child pack about 2 inches of the material in the bottom of one can. Place the half-pint jar on this and pack the material around the sides of the jar. Punch a hole through the lid of the jar and insert a thermometer. Prepare the second can, jar, and thermometer in the same way, but do not pack any of the insulating material into the can; this will serve as a control apparatus. Then quickly fill the jars with very hot water (about 180° Fahrenheit), cap the jars, and pack more material over the jar in the test apparatus. Record the thermometer reading at this time and each half-hour for the next several hours. Which setup should cool faster? *(The uninsulated container.)* If other cans, jars, and thermometers are available, several insulating materials can be tested simultaneously.

These questions will stimulate careful thinking about important concepts: "Where does the heat energy from the water go?" *(It eventually dissipates into the surrounding air and other materials.)* "Through what materials does the heat energy travel? Would the heat energy be able to escape from the water faster if the insulating material were a better conductor? if the insulating material were packed tighter? if the jar were wrapped with aluminum foil?" Encourage the children to test their answers to these questions and to raise other questions of their own.

Some extensions of the above experiences may include use of the centigrade scales on thermometers; comparison of the insulating quality of various clothing materials, commercial home-insulating materials, soil, water, air, etc.; and library research on heat insulation in space and polar exploration.

Learning: (x,y) Some materials conduct heat more slowly than others. The slower conductors are called heat insulators. They are useful in clothing, houses, food carriers, etc. to prevent the movement of heat energy into or out of something.

ACTIVITY 71 (x,y)

SEEING MATERIALS EXPAND WHEN HEATED

Purpose: To demonstrate the expansion of materials when they are heated

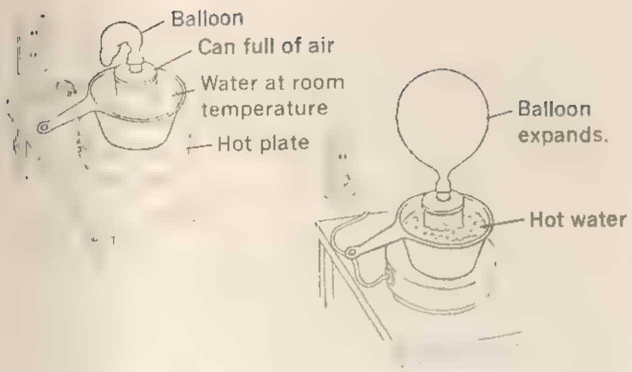
Concept to be developed: The addition of heat energy to materials causes them to expand.

Materials needed:

- Hot plate
- Pan of water
- One-hole stopper
- Glass tubing (1 foot long)
- Wooden stick
- Board (2 feet long or longer)
- File card
- Large sheet of paper
- Small can
- Balloon
- Ink or food coloring
- Tacks or nails
- Uninsulated wire (2 feet)
- Cigarette lighter

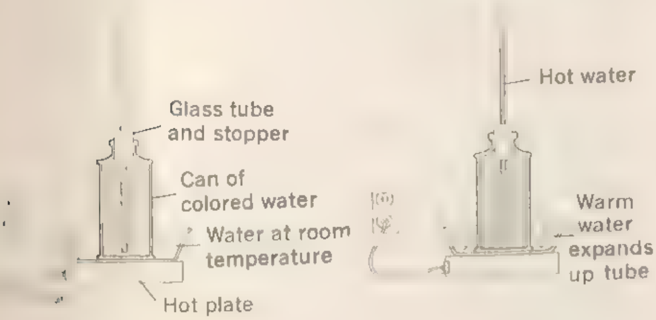
INTRODUCTION: Ask the children if they have ever opened a jar whose cover had been screwed too tightly by holding the cover under hot water. Ask them to explain why they think holding the jar under hot water helped. What do they think happened when the hot water came in contact with the metal cap? Was the metal affected in any way? Tell the children that the following Activity may help them to find answers to these questions.

Scientists are reasonably sure that a substance expands when heated because the increase in average energy of molecular motion (temperature) causes molecules to move farther apart as they collide more forcibly. You can help the children demonstrate the expansion of a gas, a liquid, and a solid wire, as described below.



Expanding Air: Have a child put the balloon over the neck of the can and immerse the can in the hot water. What happens? *(The expanding air partly inflates the balloon.)* Draw from this part of the Activity the meaning of the word *expand.* Ask, "What is happening to the balloon?" *(It is growing bigger, or expanding.)*

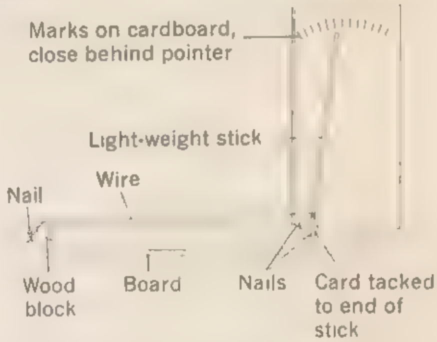
Expanding Water: Insert the glass tube into the one-hole stopper so that it extends below the stopper. Have a child fill the can with colored water, place the stopper into the neck of the can so that the tube extends below the surface of the liquid, and immerse the can in the hot water. What happens? *(The colored water expands up into the tube.)* The children may recognize this as a water thermometer. Mention again that the



water is "growing bigger" or expanding. Suggest that the children tape a file card to the back of the glass tube (adding enough colored water to partially fill the tube). On this card they can mark the height of the water in the tube when the can is in the hot water, on a window sill, in ice water, etc. They can place a real thermometer alongside the water thermometer in these situations and record real temperatures next to the marks made on the file card.

Expanding Wire: Have the children arrange the materials as shown in the illustration with the stick leaning to the right. Be sure the wire is pulled taut. Then ignite the cigarette lighter and move the flame back and forth along the wire. Have the children observe carefully the movement of the stick to the right as the wire is heated by the flame and then to the left as it cools after the burning is ended.

You can encourage interested children to find out more about the pop-up toaster release and about thermostats in home heaters and automatic irons. They work because metal expands when it is heated.



Learning: (x,y) All materials expand when heated.

ACTIVITY 72 (y)

MAKING AIR CIRCULATE BY HEATING

Purpose: To show how heat energy is carried by convection currents

Concept to be developed: When air is heated it expands and becomes lighter than it was before heating; hence, it rises.

Materials needed:

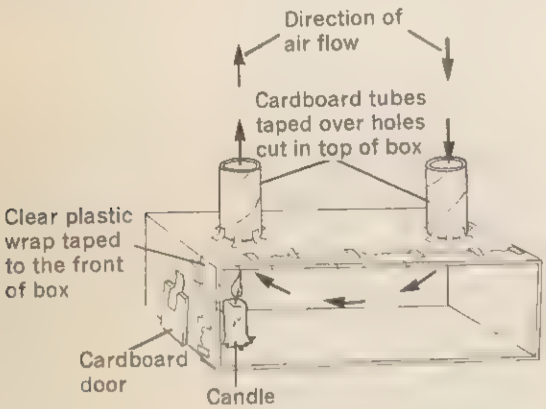
Wooden box (size of a shoebox)
Candle
Cotton clothesline (1 foot)
Transparent plastic wrap
Tape (cellophane, adhesive, or masking)
2 cardboard tubes (about 1½ inches in diameter and 6 inches long)

INTRODUCTION: To show another function of heat energy, walk over to one of the radiators in the classroom. Ask the children, "Why does the radiator become warm? How does the radiator keep the room warm?" Encourage the children to think about how the heat comes from the radiator and what happens to the air when the heat energy warms it. Describe to the children the process of convection, *in order to help them understand what a convection current is.*

Convection *is the term used to describe the way in which heating part of a body of gas (in this case, the air near the radiator) or liquid causes heated molecules to move up and away from the heating*

source, thereby carrying heat energy to areas distant from the source. This is the process used in moving heated air from radiators to distant parts of a room, in circulating air warmed by the furnace of some hot-air heating systems, in circulating water warmed by the furnace through pipes and radiators of some hot-water heating systems, and in producing winds and other currents in the atmosphere.

As the hot air rises from the radiator, cold air replaces it. This starts a current of air moving. The cold air eventually falls down to the floor and comes close to the radiator, where it is heated in turn, and so the process continues to heat the room. The children will be able to see how this works from the following Activity.



Cut two holes at opposite ends of one side of the box. Turn the box on its side so that the side with holes in it is now the "top." Use the tape to fasten the cardboard tubes over the holes and then fasten a candle inside the box directly beneath one of the holes. Cut a "door" in the end of the box closest to the candle and then cover the open side of the box with clear plastic. Light the candle through the door and tape the door shut. Light the clothesline bundle at one end and then blow out the flame, but let the bundle smolder to produce smoke. In order to see the direction of convection currents in the box, hold the smoke-maker over each cardboard tube and observe the movement of the smoke. Which way does the smoke move? *(The smoke should move down the tube opposite the candle, across the box toward the candle, and then up.)* Why? *(The air warmed by the candle expands and becomes less dense. The cooler, more dense air moves in, forcing the warm air upward.)*

Help the children compare their observations with other experiences. Ask the class, "Which way is the air moving around a hot radiator?" Test it with the smoke-maker. On a hot summer day which way is air likely to be moving over the hot beach and other land? Over the cooler water of the ocean? Does this explain why on a hot day the breeze on a beach is almost always from the ocean toward the beach? *(Yes.)*

Learnings: (x) Warm air rises. (y) Heating air causes convection currents—heated air rises and cooler air comes in to replace it. (z) Expanding air is lighter than cooler air—a volume of warm, expanded air weighs less than an equal volume of cooler air. Cool air tends to flow in under warm air, causing the warm air to rise.*

ACTIVITY 73 (y,z)

MAKING WATER MOVE BY HEATING

Purpose: To show how heat energy is carried by convection currents in liquids

Concept to be developed: Warm liquids rise because they are less dense than when they are cool.

Materials needed:

- 2 one-quart bottles
- 2 glass tubes (1-foot length)
- Food coloring or ink
- Tape (cellophane, adhesive, or masking)
- Board (about 3 feet long)
- Candle
- Plastic clay

INTRODUCTION: Review what was done in Activity 72. Ask the children, "Do you think that warm water will rise the way warm air does? How can we test it to see?"

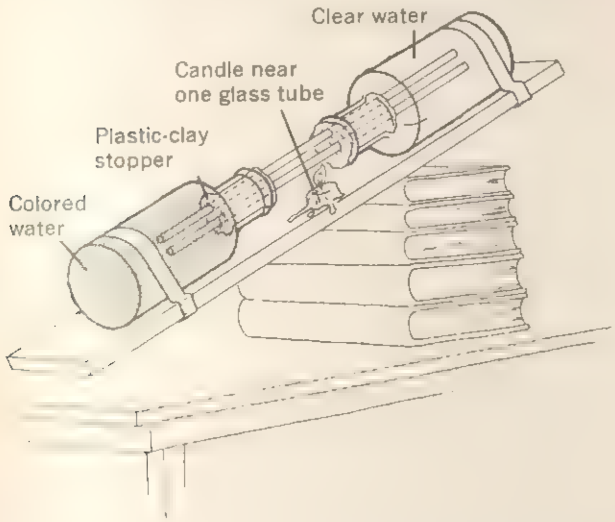
Have a child imbed two glass tubes in two plastic clay stoppers shaped carefully to fit the bottles. Fill one bottle with clear water. Fill the other with water colored deeply with food coloring or ink and tape it to the board. Fit one of the clay stoppers snugly into the bottle of clear water and fill the glass tubes with clear water. Cover the ends of the two tubes with a finger. Pick up the bottle of clear water and invert the tubes, fitting the stopper into the bottle of colored water. Be sure the tubes are horizontal so that the candle flame will heat only one of the tubes.

Tape the bottle of clear water to the board and press the clay stoppers to prevent leaks. Then light the candle to heat one of the tubes gently. Have the children observe the flow of the colored

* To encourage children to find or devise a way to compare the weights of warm and cool air, see *The Earth*, by Lawrence Hubbell (Investigating Science with Children Series; Darien, Conn., Teachers Publishing Corporation, 1964).

water. Which way does it flow? *(The colored water will flow down in the cool tube and up in the heated tube.)* Point out that this is much like a hot-water heating system with only one radiator, a very large reserve tank, a one-tube boiler, and a one-candle flame.

You can encourage the children to find out more about the heating systems in their homes. Some hot-water and hot-air systems work entirely by gravity-convection, others have pumps and/or blowers to aid gravity.



Learnings: (x) Water that is heated moves upward in a container. (y) Descending cool water, replacing the rising heated water, is the convection current that may transfer heat through a container of water.

Summing Up Ideas: Temperature and heat are not the same thing. Temperature is a measure of the average molecular energy of motion; heat is a measure of the total molecular energy of motion present. Thermometers measure temperature. Materials vary in their transparency to heat energy; colors vary in their ability to absorb or reflect heat energy. The rate at which heat travels through different materials (the rate of conduction) varies. All materials expand when heated.

WHAT ARE SOME OF THE CHARACTERISTICS OF LIGHT WAVES?

When the children ask questions such as the following, the Activities suggested in this section may help them discover some of the answers:

"Does red paint have red light in it?"

"Does your eye photograph things you see?"

"How far does your eyesight reach?"

"Where do rainbow colors come from?"

"How does a camera work? a telescope? the eye? a mirror? a periscope?"

"Why do fluorescent tubes stay cool?"

ACTIVITY 74 (x)

COMPARING SOURCES OF LIGHT

Purpose: To show the many ways light can be produced

Concept to be developed: Light energy can result from the conversion of other forms of energy.

Materials needed:

No special materials are needed.

INTRODUCTION: A lead into the study of light may come as the children learn about the ways early settlers and pioneers lived in America. You can ask them to find out about the kinds of lights that were used in houses and on streets and on vehicles from early times.

In a discussion of the different sources of light that men have used, suggest that children bring some kinds of lights for a display. Some children may bring candles, oil lamps, incandescent bulbs, fluorescent tubes, neon lamps, flashlights, torches, gas burners, carbon arc lamps, and oil lanterns.

In displaying these, the children can make label cards or a storybook page with the picture and name of each one. On each page the children might write a story telling which form of energy is converted to light. You may help the children identify the energy stored chemically in fuels, and the energy of electron flow. The story might also identify the glowing part that radiates the light. To find this information, you may guide the children in reading from science textbooks, encyclopedias, and other references. They should find that candles, lanterns, and torches have flames in which carbon particles from the fuel are burning, or changing chemically, and radiating infrared (heat) and light waves. Some of the carbon in a candle flame may be collected on a cold knife blade as soot. Electric lamp filaments and lantern mantles are materials that can be heated to very high temperatures without melting. The high temperatures cause the atoms in the filament to move rapidly, and high-energy infrared and light waves of all frequencies are produced in the atoms. In neon lights, the neon atoms produce light waves of only the few frequencies characteristic of neon, but very little of

the infrared frequencies that are so effective in heating. In fluorescent tubes, electron movement causes ultraviolet waves (which are invisible) to strike the atoms of the coating and cause them to produce many frequencies of visible light waves.

During discussions of the children's findings, review the chart of electromagnetic waves at the end of chapter 4. Bring out the idea that infrared, radio, light, ultraviolet, and other waves are much alike, differing only in frequency (and wavelength), and that each type of wave is a form of energy, which can be converted from other forms and into other forms.

ACTIVITY 75 (x,y)

MAKING SHADOWS

Purpose: To show that shadows result from the absence of light

Concept to be developed: Light rays travel in straight lines and do not bend to fill in an area where light rays are not present.

Materials needed:

- Gooseneck lamp or spring-clamp socket reflector lamp (150-watt, indoor type)
- Extension cord
- Sheet
- Newsprint or brown paper
- Clothesline

INTRODUCTION: Point the reflector lamp at a light-colored wall about 6 feet away. Make "animal shadows" with your hands. Ask the children, "Why do the shadows appear on the wall? What is a shadow?" Establish that a shadow is actually an absence of light. Then discuss the kinds and sorts of shadows that can be made. Stress that the children should observe shadows carefully because shadows will tell them some more interesting facts about light.

Point out that shadows of objects made in the light of a small or distant source have sharp edges and their shapes resemble the objects. This indicates that light waves do not turn corners, that they travel in straight lines. If this were not true, light would fill in the object's shadow.

In a darkened hallway hold the reflector lamp high and have the children observe their shadows. What happens as they walk down the hall? What happens if the lamp is raised or lowered.

Place the reflector lamp in one corner at the front of a darkened room. Stretch the clothesline between nails across the corner, about 10 feet in front of the lamp. Hang the sheet on the line as a screen. Actors behind the screen may perform for the audience on the other side of the screen.

Have a child sit beside a large piece of paper taped to the wall. Point the lamp toward him and have another child trace his silhouette on the paper.

In each of these experiences point out that the light does not go around behind the object making the shadow. Light waves travel in straight lines. You may want to have some children read to find out about shadows, glare, and eye strain. A demonstration of difference in shadow contrast or glare from several light sources may be shown. Point out that a tiny, intense light source makes the most contrasting shadows. It also makes the most glare. Ask the class, "Which kind of source is best for each of the experiences above?"

Learnings: (x) Light rays travel in straight lines. (x) Shadows are caused by the blocking of light.

ACTIVITY 76 (x)

TRYING TO SEE AROUND CORNERS

Purpose: To reinforce the concept that light rays travel in straight lines

Concept to be developed: Light rays do not bend, but travel in straight lines.

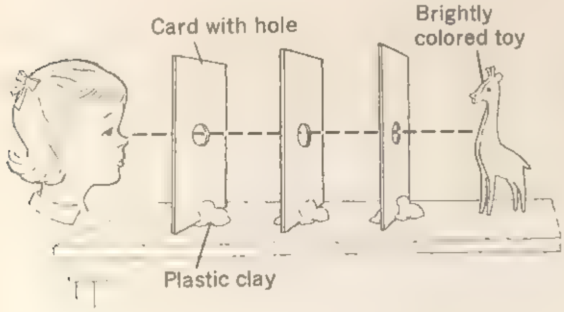
Materials needed:

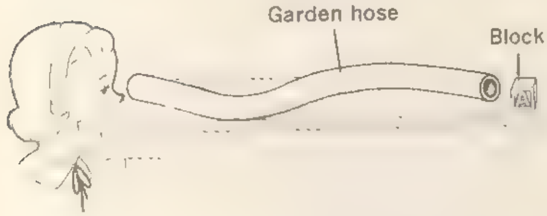
- Garden hose or vacuum-cleaner tube
- File cards (about 5 by 8 inches)
- Plastic clay
- Child's toy
- Wooden block

INTRODUCTION: Children may further test the idea that light waves travel in straight lines in this way. Ask a child to stand in the doorway of the classroom. Ask the other children if they can see him. Then have the child step to one side, out of sight of the other children. Ask the children, "Can you see him now? Why not?" Of course the children will say that the wall is in the way. But try to have them see that the wall is really having some effect upon the light waves, which would help them to see the child otherwise. What is the wall doing to the light waves? What does this show about light waves? For answers, have the children perform the following Activity.

Have the children draw a straight chalk line on a table top. Then cut small holes in the middle of each of the cards and mount them along the line on pieces of clay as in the illustration. Can

a child see the toy through the three holes? *(Yes, but only if the path of light through them is a straight line.)* Try moving the middle card 1 inch to the left. Now can the child see the toy? *(No.)*





The children may try a variation of this by trying to see a block when looking through a garden hose or vacuum-cleaner tube. Only when the hose is perfectly straight can the light from the block come through.

Learnings: (x) Light travels in straight lines. (x) Light cannot travel around corners.

ACTIVITY 77 (z)

MEASURING ANGLES OF REFLECTION FROM A MIRROR

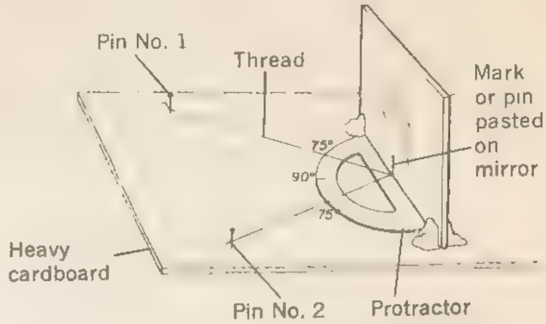
Purpose: To demonstrate that light can be reflected by a mirror

Concept to be developed: The angle at which light is reflected from a mirror is equal to the angle at which it strikes the mirror.

Materials needed:

Mirror
Pins
Protractor
Plastic clay
Thread
Household cement
Cardboard (8 by 10 inches or larger)

INTRODUCTION: Tell the children that now they are going to see another characteristic of light waves. Place any unsymmetrical object on your desk and hold a large mirror behind it so that the mirror is facing the children. Ask different children to describe in detail what they see in the mirror. Ask the children, "Why do children in different parts of the room see different views of the object?" As they answer that they are looking at the mirror from the side, or the back, or the middle of the room, etc., develop the meaning of the phrase at an angle *and then proceed with the Activity.*



Have the children arrange the materials as shown in the illustration. The protractor has two threads cemented to its center point. A straight pin is cemented or tied to the end of each thread. With the protractor edge against the mirror, have a child stretch either one of the threads taut and stick pin No. 1 at random into the cardboard. Then he may sight with one eye until he sees the reflection of the pin over the center mark on the mirror. Stretch the thread of pin No. 2 so that it is in his line of sight to the reflection and stick that pin in the cardboard. The angles from the mirror to each thread should be the same, no matter where pin No. 1 has been placed.

Learning: (z) Children may state the concept "The angle between a mirror and the path of light from an object to the mirror is equal to the angle between the mirror and the path of light reflected from the mirror."

ACTIVITY 78 (y,z)

MAKING A PERISCOPE

Purpose: To show how the reflecting properties of mirrors can be used in a device that enables us to "see around corners"

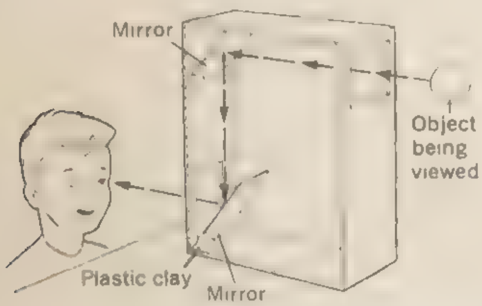
Concept to be developed: The angle at which light is reflected from a mirror is equal to the angle at which it strikes the mirror.

Materials needed:

Cardboard box (long shoebox or umbrella box)
2 pocket mirrors
Plastic clay

INTRODUCTION: Review with the children the fact that light waves are blocked off by objects such as the wall or the door because light cannot go around corners. Then show a picture of a submarine to the children. Ask how the sailors inside the submarine can see what is happening on the surface of the water when the submarine is submerged. When a child mentions a periscope, ask, "But how could the light waves get through all the parts of the submarine and the water so as to make it possible for the sailors to see?"

Have the children cut holes, 2 inches square, in the box as shown in the illustration. Mount the



mirrors in the corners, using plastic clay as needed. Adjust the mirrors at angles of about 45°. The reflections of objects can then be seen by a child looking in the lower opening. Have the children tape the box lid in place and let them discover how periscopes allow a person to see around corners without being seen.

Learning: (x) The path of a ray of light can be bent by mirrors.

ACTIVITY 79 (z)

MEASURING DISTANCES WITH MIRRORS

Purpose: To show how the reflecting properties of mirrors can be used in a device to measure distance

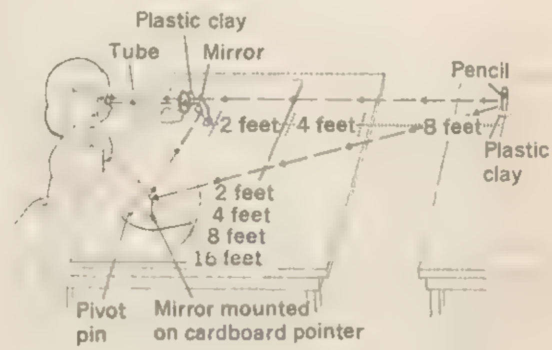
Concept to be developed: The angle at which light is reflected from a mirror is equal to the angle at which it strikes the mirror.

Materials needed:

Corrugated cardboard (about 1 by 2 feet)
Cardboard tube (about 4 inches long)
2 pocket mirrors
Plastic clay
Straight pin

INTRODUCTION: Tell the children that the fact that light has the property of reflection helps people, since they can take advantage of light reflection to make useful devices. One of them they have already seen—the periscope. Another device is part of a camera. Show the children a camera with a range finder. Allow the children to look through the range finder and to estimate some distances with it. Then ask the children to explain how they think a range finder works.

Have the children cut out the cardboard pointer and attach it to the large cardboard base using one straight pin. They can then use plastic clay to mount the mirrors and tubes approximately as shown in the illustration. To measure distances, the children must calibrate a scale at the pointer in this way. Place a pencil upright in clay about 8 feet from the fixed mirror. Have a child look through the tube toward the pencil. Turn the pointer until he can see the



pencil reflected by the mirrors directly below the part of the pencil he can see over the top of the fixed mirror. Mark "8 feet" at this pointer position. Only at this pointer position can the child see the reflected pencil directly under the real pencil. Make marks in the same way for the pointer positions when the pencil is 4 feet, 2 feet, etc. from the fixed mirror.

Encourage some of the children to complete the scale on the distance measurer out to 20 feet. Then they should measure the distances to some objects in the room whose distances are not known. The procedure is to sight through the tube toward the object and move the pivoted mirror until the reflection in the fixed mirror lines up under the object. Have them check these measurements with a ruler or tape measure.

For extended coverage of this subject with interested children, suggest that they find books about how mirrors are used in the range finders of some cameras and in gunnery. The children may find that mirrors in range finders are sometimes unsilvered or lightly silvered. Why? *(A*

fully silvered mirror reflects almost all the light that comes to it; therefore, images in it appear very bright. Lightly silvered or unsilvered glass will reflect some of the light coming to it, but much will pass through, so the reflected image is dim but can be seen if the background is dark.)

Learning: (z) Some range finders use mirrors to align images.

ACTIVITY 80 (y,z)

SEEING LIGHT BEND IN WATER

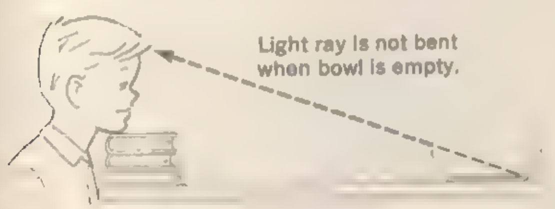
Purpose: To show how a ray of light bends as it passes from one transparent material to another

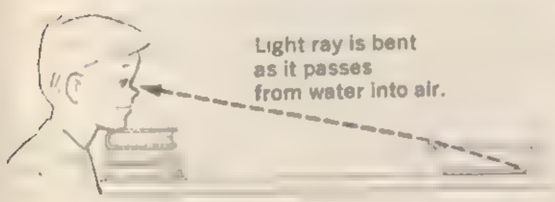
Concept to be developed: Light is refracted (bent) as it passes from one medium to another.

Materials needed:

- Cardboard (2 inches square)
- Slide projector
- Few drops of milk
- Chalk eraser
- Cereal bowl
- Coin
- Aquarium

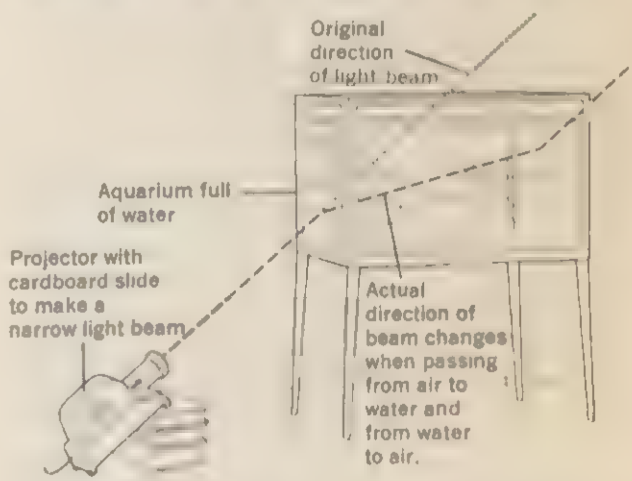
INTRODUCTION: Introduce the children to the idea that although they have seen that light waves travel in a straight line, they are now ready to proceed from there and to learn a new word, refraction, *which describes another property that light waves have. Refraction is the name given to the bending of the path of light waves as they pass from one substance into another, as from air into water or glass. The effect of refraction often is to cause objects to seem displaced. A pencil partly in a glass of water seems bent or broken, an object under water appears to be closer to the surface than it is.*





Put a coin in the cereal bowl and then have a child look over the edge of the bowl. (Place the coin so it is just a little too close to the edge of the empty bowl for the child to see it.) Then, fill the bowl with water. What happens? *(The child will see the coin appear.)* Why is the coin seen after the water is added? *(Light rays are bent or refracted as they pass from water into air, as shown in the illustration.)*

A more graphic method of showing the refraction of light rays requires the use of an aquarium and a slide projector. Fill the aquarium with water and add a few drops of milk to make the water slightly opaque. Darken the room and turn on the slide projector, aiming the beam of light from it at the aquarium. Can the children see the beam of light? *(The beam of light should be visible in the milky water; if it is not, add milk until it is.)* Have a child clap two chalk erasers together between the projector and the aquarium. Can the children see the beam of light coming from the projector? *(Yes. It is reflected by the chalk dust.)* Does the beam of light bend when it enters the water? *(Yes.)* Have a child clap the erasers together on the other side of the aquarium. Can you see the beam of light as it leaves the aquarium? *(Yes. It is reflected by the chalk dust.)* Does the beam of light bend again?



(Yes.) In which direction? *(The beam of light bends downward when passing from the air into the water and upward when passing from the water into the air.)*

Learning: (y,z) Light is refracted as it passes from one medium to another.

You may suggest that some children find out more about the direction and amount of the bending as light rays enter the water at various angles. A physics book may be the best source.

ACTIVITY 81 (x)

SEEING THE COLORS IN WHITE LIGHT THROUGH A PRISM

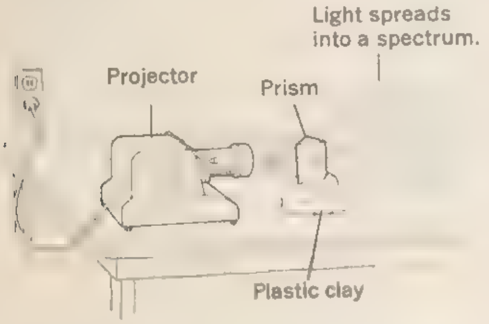
Purpose: To show that the different frequencies of light are bent by varying amounts when passing between different mediums

Concept to be developed: White light is composed of light waves of different frequencies.

Materials needed:

Large glass prism
Slide projector
Plastic clay
File card

INTRODUCTION: Remind the children that in Activity 80 they saw that light waves can be bent. But ask, "Are the light waves all bent in the same direction, that is, to the same degree? What causes refraction of light to vary?" Then show the children a picture of a rainbow. Ask them, "Why do we see rainbows?" Give the children a chance to advance their theories. The next Activity may provide answers to their questions.



Have the children place the slide projector on a table about 6 feet from the front of a darkened room. Cut the card to form a 2-inch-square slide and cut a narrow, ⅛- by 1-inch slit in the middle. Insert the slide, with slit up and down, in the projector. Mount the prism on a piece of clay so the projector light shines through it as in the drawing. Somewhere on the wall a small rainbow, or spectrum of all the rainbow colors, should appear. Have a child hold a sheet of white paper against the wall where the spectrum appears so the colors can be seen distinctly. Why do the colors appear? *(In passing into and out of glass through surfaces at certain angles, light waves are bent, or refracted. The various frequencies or colors are bent by different amounts—blues the most, reds the least. They then appear separated as in a rainbow.)*

You may help children find information to answer these questions: How is the spectrum formed as sunlight passes through an aquarium? How is a rainbow formed? How does a diffraction grating form a spectrum? Can colors be put together to make white light?

Learnings: (x) White light may be composed of all the colors (frequencies) of the spectrum. (x,y) When light passes into and out of a prism, the different frequencies of visible light are bent by varying amounts.

ACTIVITY 82 (z)

MAKING A SPECTROSCOPE

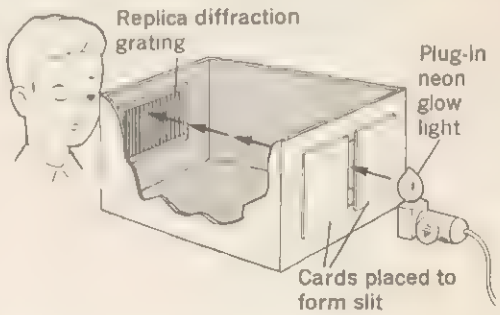
Purpose: To demonstrate how the light spectrum of a material can be used to identify it

Concept to be developed: Not all sources of white light produce spectra that have all the colors of the rainbow.

Materials needed:

Neon glow lamp (¼-watt, plug-in type, such as GE 3960)
25-watt lamp bulb with plug-in socket
½-inch square of replica diffraction grating, about 15,000 lines per inch or a glass prism
Tape (cellophane, adhesive, or masking)
Shoebox
Extension cord
File cards
Mercury-vapor lamp

INTRODUCTION: Show the neon glow lamp and the 25-watt bulb to the children. Then show them a picture of a color spectrum. Ask the children, "Will both of these bulbs produce light of all the colors of the spectrum? Why do you think so?" Ask them to advance their ideas on how they can tell the colors the bulbs will produce. Mention that there is a device called a spectroscope that breaks the light from a given source into a spectrum, and proceed in the following way to show them how to make it.



Children can make a spectroscope, such as the one in the illustration, quite easily. Have the children cut a hole in each end of the shoebox. Tape the diffraction grating over one hole and two cards over the other hole to form a vertical slit that is no wider than one-eighth inch. Tape the cover on the box and have a child look through the grating toward a lighted lamp bulb

held near the slit. What does he see? *(He should see a complete spectrum on each side of the slit; if the spectrum does not appear, the grating must be removed, given a quarter-turn, and re-taped in place.)* What does the child see when the neon glow lamp is held in front of the slit? *(He should see a series of vertical lines of certain colors, not all the colors of the rainbow, where the complete spectrum had appeared before.)* What are the colors he sees? *(There are lines of green, yellow, and red. These are the pure colors, the separate, unmixed frequencies that are produced by electrons in neon atoms. When all the colors appear, we call the spectrum "continuous"; when only some of the colors appear, as with the neon glow lamp, we call it a "discontinuous" or a "line" spectrum.)* Other gas glow lamps, such as mercury-vapor lamps, produce other frequencies characteristic of the atoms of their gases. If gas glow lamps other than the neon lamp are available, the children should look at these through the spectroscope also.

If a diffraction grating is unavailable, you can help some of the children to substitute a glass prism for it in the spectroscope. Let them do research in the library and then try their suggestions for properly positioning the prism in the box.

In discussions bring out that in passing through both the diffraction grating and the prism the light path is bent. However, the various frequencies of light are bent different amounts, so the colors appear as the spectrum.

Learnings: (y,z) Prisms and diffraction gratings break up visible light into its component frequencies (colors) by bending the light waves. (z) A continuous spectrum displays all the colors of the rainbow; a discontinuous (line) spectrum displays only some of the colors.

ACTIVITY 83 (x)

REFLECTING SPECIFIC COLORS FROM WHITE LIGHT

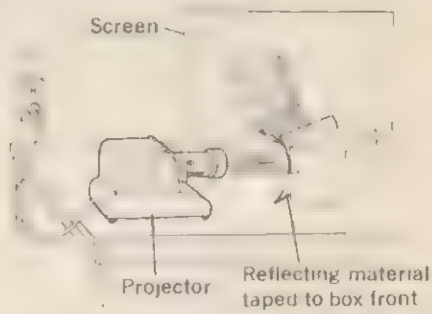
Purpose: To show that colored surfaces reflect only their own color (frequency) light rays

Concept to be developed: Materials appear to have a certain color because they reflect light of only that color (frequency) to the eye.

Materials needed:

Tape (cellophane, adhesive, or masking)
Construction paper (several different colors)
Slide projector
Cardboard box

INTRODUCTION: Darken the room by pulling the shades and turning off the lights. Have a child stand in front of the other children and hold a piece of red construction paper in his hands. Shine the light from the slide projector on the construction paper. Ask the children, "Since we are shining white light on the paper, why does it look red instead of white?" Perhaps some of the children will begin to talk about the frequency of light waves, light reflection, and other properties of light.



Have the children place a slide projector on a table in a darkened room, near a white wall or screen as shown in the illustration. Bring various colors of paper in front of it in such a way that light is reflected onto the screen or wall. Point out in the discussion that each color reflects its own color (frequency) of light, though the source is white light. Why? *(White light is a mixture of frequencies. Dyes, inks, and paints are materials that have the ability to absorb certain frequencies and to reflect certain others. The frequencies that are absorbed are converted to some other form of energy—often the infrared frequencies of electromagnetic radiation that cause heating.)*

Learnings: (x) White light is a mixture of frequencies of electromagnetic radiation. (x) Dyes, inks, and paints are materials that reflect certain frequencies and absorb others.

ACTIVITY 84 (y,z)

WORKING WITH LENSES

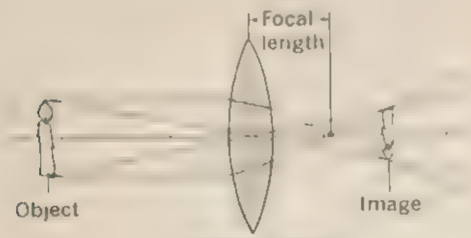
Purpose: To show how lenses are used to "control" light waves

Concept to be developed: Light waves are bent when passing through lenses.

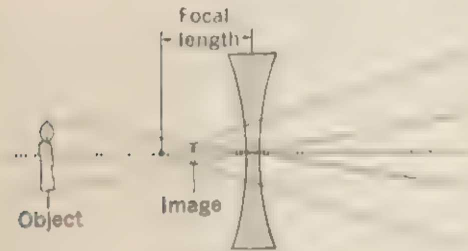
Materials needed:

Lenses: from eyeglasses, hand magnifiers, jeweler's loupe, linen counter, stamp collector's magnifier, slide projector, etc.
Tape (cellophane, masking, or adhesive)
Plastic clay
Yardstick
File card

INTRODUCTION: The lenses children are most familiar with are those in eyeglasses and hand magnifiers. This Activity is intended to help children develop concepts about the behavior of light passing through lenses. Explain to the children that there are two basic types of lenses—convex and concave.

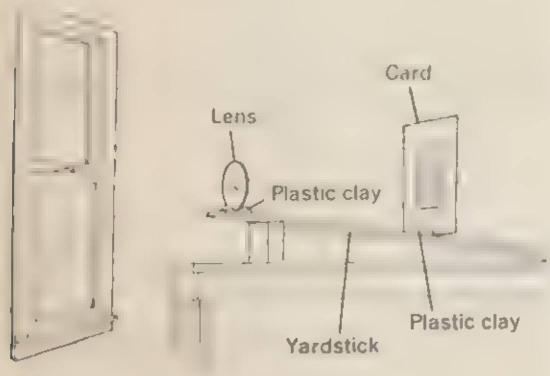


CONVEX LENS



CONCAVE LENS

Convex lenses are important in the construction and operation of cameras, telescopes, and microscopes and in understanding the structure of the eye. Concave lenses are important in the correction of eye defects and in the construction of highly corrected optical systems. Mention that it is by means of these lenses that light waves can be controlled.



Help the children arrange materials, as shown in the illustration, on the side of the room opposite the windows and point the yardstick toward a bright object outside a window. Turn off the lights in the room and close all the window blinds except those at the window being used, for too much light makes the image appear dim. The image of the bright object will appear on the card when you slide the card to the point where its distance from the lens is approximately the *focal length* of the lens. If an image cannot be formed on the card, the lens is concave; if a concave lens is available, point out to the children the differences between it and a convex lens.

The focal length of a lens is most important in determining its use. Have a child use the card and yardstick to measure the approximate focal length of several convex lenses. Write the focal length in inches on a small label and stick it to the edge of each lens. As the children discuss their findings, bring out these relationships:

- Lenses of various diameters may have the same focal length.
- Lenses of more curvature (thickness) are the stronger magnifiers and have the shorter focal lengths.
- Lenses of shorter focal lengths form the smaller images on the card.
- Lenses of the same focal length, but different diameters, form the same size images, although the image formed by the one of larger diameter is brighter.
- The image formed by a single convex lens is inverted (upside down).

Learnings: (x) Light rays bend when passing through lenses. (y,z) There are two types of lenses, convex and concave. (y,z) Convex lenses form "real" images, that is, images that can be projected onto another surface; concave lenses form "virtual" images, that is, images that cannot be projected onto another surface. (y,z) Images produced by a single convex lens are inverted (upside down).

ACTIVITY 85 (y,z)

MAKING A VIEWING CAMERA

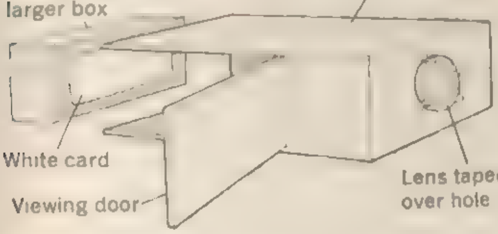
Purpose: To show how lenses are used in cameras

Concept to be developed: A camera lens focuses the image on the film.

Materials needed:

Lens, from magnifier (about 6-inch focal length)
Cardboard box (about 8 by 5 by 5 inches)
Small cardboard box or wooden block to slide inside the larger box
Tape (cellophane, adhesive, or masking)
White card (at least 4 inches square)

INTRODUCTION: Show a camera to the children. Hold the camera so that they can see the lens. Ask the children, "What is the purpose of the lens?"



Some children might like to construct a viewing camera. A simple construction is shown in the illustration. Children will discover that when the sliding card-support box or block is moved to approximately the focal length from the lens, the images of bright objects in front of the lens will be clear. In a film camera the film is in the position of the card and a shutter allows the lens to be uncovered for a fraction of a second when taking the picture.

Some of the children will be surprised that the image on the card moves, is in color, and is upside down.

Learning: (y) The image produced by a camera lens is inverted (upside down).

ACTIVITY 86 (y,z)

ASSEMBLING A TWO-LENS HAND TELESCOPE

Purpose: To show how lenses are used in simple telescopes

Concept to be developed: The power (strength) of a telescope is a function of the focal length of its lenses.

Materials needed:

Lens, 10- to 20-inch focal length (objective)
Lens, 1- to 2-inch focal length (eyepiece)
2 telescoping cardboard tubes, the length of which is greater than the sum of the focal lengths of the lenses
Tape (cellophane, adhesive, or masking)

INTRODUCTION: Show the children a picture of a telescope or of a man using a telescope. Ask them to explain how the lenses in the telescope make objects appear closer. Ask the children, "Why are two lenses used in the telescope?" In order to answer this question, several children might like to construct a telescope similar to the one shown in the illustration. They will discover that the objects viewed are inverted by the lens system used here, which is the one used in astronomical telescopes.

The objective lens forms an inverted image at its focal point inside the tubes. The eyepiece lens simply magnifies the image formed. The "power" of the telescope is the quotient of the objective lens focal length divided by the eyepiece lens focal length, or

$$\text{Power} = \frac{\text{Focal Length of Object Lens}}{\text{Focal Length of Eyepiece Lens}}$$

A ten-power telescope is adequate for observing craters of the Moon, the moons of Jupiter, etc. One of more than ten power may require a steadier mount than children's hands.

To expand this Activity, you may wish to direct children to read, to observe, and to experiment further in discovering how convex lenses function in projectors, microscopes, and the eye.

Learnings: (x,y) The image produced by astronomical telescopes is inverted. (y,z) The power of a telescope is a function of the focal length of its lenses.

Summing Up Ideas: Light rays travel in a straight line. Shadows are caused by an absence of light. Light rays cannot travel around corners. The angle between a mirror and the path of light from an object to the mirror is equal to the angle between the mirror and the path of light reflected from the mirror. White light is a mixture of different frequencies of electromagnetic radiation (colors). When light rays pass through a prism or diffraction grating, the various frequencies (colors) are bent by different amounts, for light rays are refracted (bent) as they pass from one medium to another. There are two types of lenses, convex and concave. The image produced by a single convex lens is inverted.

HOW CAN HEAT AND LIGHT BE CONVERTED INTO OTHER FORMS OF ENERGY?

Heat and light energy can be converted into other forms of energy, or they can be used to perform

work. In this way they conform to the general rule of conservation of energy. Both of these forms of energy can be converted to electrical energy, to chemical energy, and to mechanical energy.

ACTIVITY 87 (x,y,z)

SEEING HEAT ENERGY MOVE OBJECTS

Purpose: To show that heat energy can do work in moving objects

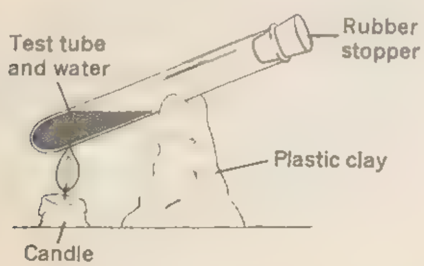
Concept to be developed: Heat energy can be converted to mechanical energy.

Materials needed:

Clean can with tight press-on lid
Disk of metal (from the top of a can)
Hot plate
Plastic clay
Test tube
Candle
Coat hanger

INTRODUCTION: Explain to the children that work is done by heat energy in heat engines, such as steam engines, gasoline engines, and rockets. For example, in a steam engine, the burning fuel gives the molecules of steam high energy of motion. The high energy of motion causes increased molecular collisions in the steam boiler. This high rate of collision causes the gas to exert high pressure on its container. The high pressure is used to cause a piston to move in the steam engine. It may also turn a turbine wheel, as in steam turbines (or generators). The same process of work done by heat energy is also generally responsible for the way gasoline and rocket engines operate.

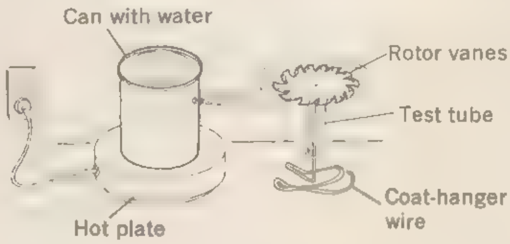
Mention to the children that they can build a simple form of steam engine to see how this process works. Children will discover that considerable work can be performed by heat energy in a "steam cannon." This can be constructed in the following way. Put one tablespoonful of water in

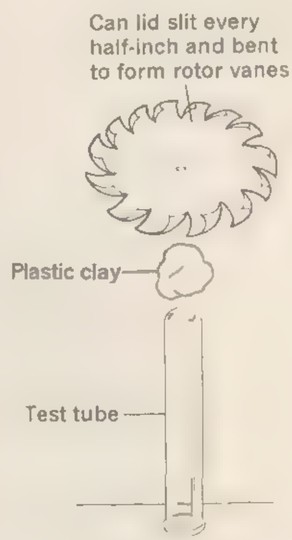


a test tube and mount it in plastic clay as shown in the illustration. Insert a plastic-clay stopper firmly (but not too tightly) and place the lighted candle under the end of the test tube "cannon." Be sure it is pointed safely toward an empty area. What happens? *(The stopper pops out.)* Why? *(Steam molecules have gained high energy of motion. Their collisions cause high pressure that pushes the stopper.)* Where does the increased energy in the steam come from? *(Heat energy of the burning candle is converted to increased energy of motion of steam molecules.)*

In discussion with the children you can point out that pistons and cylinders of gasoline and steam engines are similar to the stopper and test tube of the "steam cannon."

Another group of children can construct the steam turbine shown in the illustration. The boiler





is a can that must have a lid that can pop off if steam pressure becomes too high. Have a child punch a tiny nail hole in the side of the can as shown. Bend the coat-hanger wire to form the stand and spindle. The rotor vanes (blades) must be in line with the hole in the can as shown. Have the children carefully observe what takes place when the hot plate is turned on. Challenge them to describe the energy transformations that occur:

• Energy of electron flow in the hot plate, which causes—

• Increased energy of molecular motion of the hot plate, which causes—

• Increased energy of molecular motion of the can bottom and the water in the can. The fastest-moving water molecules form steam above the water and their high energy of motion causes high collision rate or pressure inside the can.

• High energy steam molecules escape through the hole, strike the rotor vanes, and some of the steam energy transforms to—

• Mechanical energy (of rotation) of the rotor.

Learnings: (x) Heat energy can be converted to mechanical energy. (x) Energy is conserved.

ACTIVITY 88 (z)

MAKING BURNING FUEL MOVE A ROCKET

Purpose: To demonstrate how heat energy can be used to move a rocket

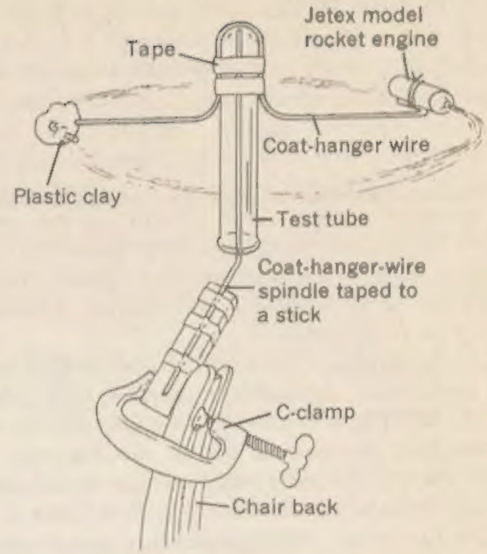
Concept to be developed: Heat energy can be converted to mechanical energy.

Materials needed:

Model rocket engine, fuel, and igniter (Kit can be purchased for about $1.50 at hobby shops.)
Tape (cellophane, adhesive, or masking)
Stick (1 by 2 by 6 inches)
C-clamp
Coat-hanger wire
Plastic clay
Test tube
Thin wire (1-foot length)

INTRODUCTION: Show the children a picture of a rocket or missile being launched. Ask the children what kinds of energy they can identify present in the picture. Ask them what type of energy they think is causing the rocket to move. Is it similar in any way to the heat energy that causes a steam or gasoline engine to move? They can construct a simple rocket themselves to discover the answer.

Have several children work together in preparing the rocket test stand as shown in the illustration. The coat-hanger-wire spindle is taped firmly to the stick and then clamped to a chair back. The rotating parts are supported on an inverted test tube free to turn on the spindle. Bend and tape the wire arm to the test tube as shown. Fasten the rocket engine to the coat-hanger-wire arm with several turns of thin wire, twisted tight. A lump of plastic clay is hooked onto the other end of the arm to balance the rocket engine's weight. The rocket engine should be fueled and ready to ignite according to the manufacturer's directions before attaching it to the arm.



Ignite the rocket fuel and have the children observe the motion produced. Help them recognize these energy changes:

• Energy stored chemically in the fuel is released in burning and causes—

• Increased energy of motion of molecules (heat energy) of the fuel. High-energy burning fuel particles accelerate and escape to the rear through the opening, transferring some of their energy into—

• Energy of motion of the engine.*

Learnings: (x) Heat energy can be converted to mechanical energy. (x) Energy is conserved.

ACTIVITY 89 (y,z)

CONVERTING LIGHT ENERGY TO ELECTRICAL ENERGY

Purpose: To show that energy from the Sun can be used for power

Concept to be developed: Light energy can be converted into electrical energy.

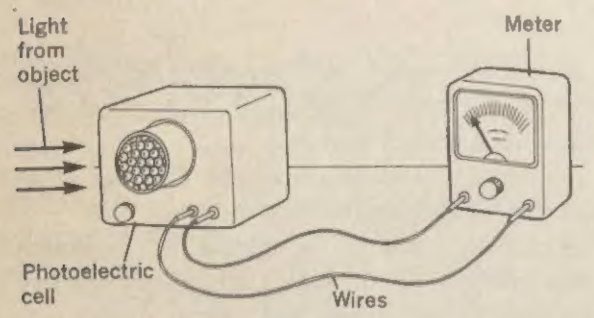
Materials needed:

Photographer's exposure meter

* For further information and activities for children interested in forces and motion see *Motion*, by Lois Dunn (Investigating Science with Children Series; Darien, Conn., Teachers Publishing Corporation, 1964). Other children may find answers to their questions about the use of rocket engines in space exploration in *Space*, by Arthur Costa, in the same series.

INTRODUCTION: Explain to the children that space exploration has led to the development of very interesting uses of light and heat energy. For instance, scientists have developed materials in which light and/or heat radiations (energy) are converted directly into electrical energy. Introduce the words that describe such materials: photoelectric *materials, in which light energy is converted directly into electrical energy, and* thermoelectric *materials, in which heat energy is converted directly into electrical energy. Point out the use of* photo, *relating to light (as in photograph), and* thermo *relating to heat (as in thermometer).*

Go on to explain how some of our weather satellites are almost completely covered with photoelectric cells. These convert the sunlight directly into electron flow in order to charge the batteries that operate the satellite radio and television broadcasters. How a photoelectric cell works will be seen if the children examine a photographer's exposure meter.



Inside the exposure meter are the parts connected as shown in the illustration. Light intensity registers on the dial of an electric meter. The more light energy striking the photoelectric cell, the more electric flow there is through the meter. Have children point the exposure meter close to objects of various brightnesses in the sunlight. Observe the movement of the meter needle.

Point out that light energy is converted to electrical energy without the use of any machinery or fuel in the photoelectric cell. Help the children find out how complex some other electrical energy producers (dynamos, storage batteries, etc.) are by comparison.

Learnings: (x) Light energy can be converted to electrical energy. (x) Energy is conserved.

ACTIVITY 90 (y,z)

CONVERTING HEAT ENERGY TO ELECTRICAL ENERGY

Purpose: To demonstrate the principle of the thermocouple

Concept to be developed: Heat energy can be converted to electrical energy.

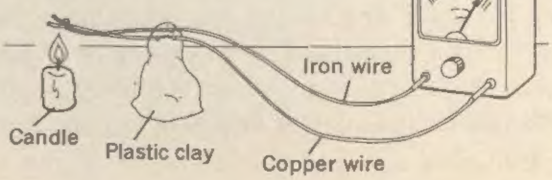
Materials needed:

Galvanometer, milliameter, or microammeter (or device such as the one made in Activity 58)
Iron wire (6-foot length)
Copper wire (6-foot length)
Candle
Asbestos, 6 inches square

INTRODUCTION: Remind the children that they have seen how light energy can be converted to electrical energy in Activity 89. Now they will discover what process is needed to convert heat energy to electrical energy. Mention that they will understand this if they consider another problem that the weather satellite in space encounters as it whirls around in its orbit.

When satellites are on the dark side of a planet or moon or far from the sun, the photocells do not receive enough light energy to produce the electrical energy needed. Storage batteries are used to provide current when the solar cells are not in sunlight. Also, a number of nuclear power systems are under development, or are in use, to circumvent the limitations of solar power supplies. The program for this development, being carried out by the National Aeronautics and Space Administration and the Atomic Energy Commission, is called SNAP (Systems for Nuclear Auxiliary Power). A typical SNAP unit consists of a small reactor (heat conversion unit) with a long-life radioactive "fuel," which converts nuclear energy to heat. Surrounding the reactor are many thermoelectric units that convert heat energy into electron flow. Your children can convert some electrical energy from heat by constructing the simple device in this Activity. Tell the children that the device they will make is called a *thermocouple.* Ask them to guess what this word might mean and then what materials they think might be joined.

A thermocouple is the simplest thermoelectric device; it can be made by the junction of two



unlike metals. Help the children obtain two kinds of wire, such as iron and copper. Connect the two to a sensitive electric meter. Twist the other ends of the wires together. Hold the junction of the wires (thermocouple) over a candle flame. Electron flow should be registered by the meter.

You might ask such questions as "What kind of energy comes from the candle?" *(Heat energy.)* "What happens in the thermocouple?" *(Heat energy is converted to electrical energy.)*

Some of the children might like to explore the use of thermocouples further. Several children could try to find out how a thermocouple is used in an automatic gas water heater. You might call on the local gas company to help answer this.

Learnings: (x) Heat energy may be converted to electrical energy. (x) Energy is conserved.

ACTIVITY 91 (x,y,z)

MAKING LIGHT PRINT A PICTURE

Purpose: To show how light energy is used in making photographs

Concept to be developed: Light energy can be converted into chemical energy.

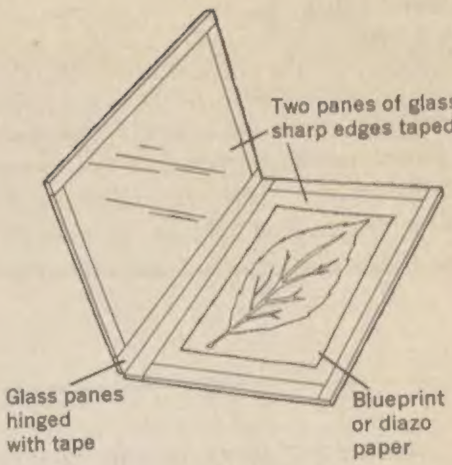
Materials needed:

- 2 panes of glass
- Wide-mouth jar
- Pan of water
- Household ammonia
- Tape (cellophane, adhesive, or masking)
- Blueprint paper and/or diazo paper (ammonia developing) from drafting and blueprint supply store

INTRODUCTION: Mention to the children that in addition to being convertible into electrical energy, light waves can be converted into chemical energy. This process is seen most clearly in photography, in which photographic films and papers are coated with substances, and light causes changes of the substances. On a photographic print (or picture) dark and light areas result because large and small amounts of light were allowed to strike the paper through the film. Blueprint and diazo papers are not as sensitive to light as some materials, but the children must keep them covered when near windows or bright light. The children can test the process in this Activity.

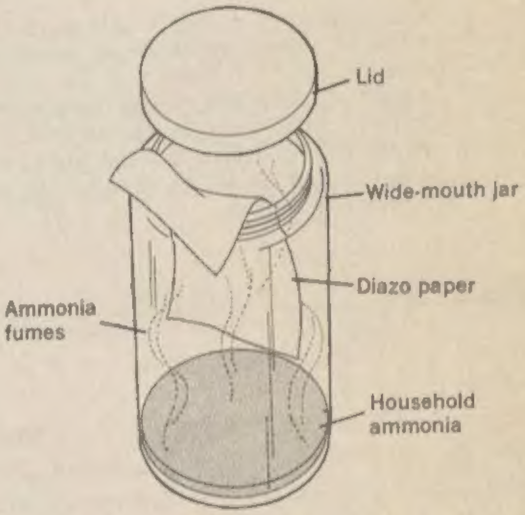
The steps in making a print are as follows:

For blueprint paper: Place a sheet of blueprint paper, greenish side up, on one of the glass panes; lay the object to be printed on the paper as in the illustration; a photo negative, leaf, or piece of lace will work well. Hold these in place with the second pane of glass. Expose them to the sun



for a period of 20 seconds to several minutes, depending on the brightness of the sky. Then wash the blueprint paper by placing it in a pan of water for several minutes. This removes all the remaining light-sensitive substance. Lay it on a smooth flat table to dry.

For diazo paper: The procedure is the same as for blueprint paper up to the step of washing. Do not wash the paper in water. Instead, expose



it to ammonia *fumes* in a large jar for several minutes. Then light can make no further changes on the paper.

These experiences may open the door for some children to work with the more sensitive photographic materials used with cameras. Refer to local photo supply stores for more information about developing photographic films and prints.

Learnings (x) Light energy can be converted to chemical energy. (x) Energy is conserved.

PHOTOSYNTHESIS

In closing this chapter we can only mention the conversion of light energy to chemical energy in wood and other plant and animal substances. All green plants, including many of the foods that provide energy for our bodies, contain chlorophyll, which reacts with light energy from the Sun and rearranges atoms in water and carbon dioxide molecules to form sugars and starches. Sugars and starches convert their stored chemical energy back into light and heat as they burn, becoming molecules of water and carbon dioxide with high energy of motion (heat).*

* You will find more information and classroom activities on photosynthesis in *Living Things,* by James Wailes (Investigating Science with Children Series; Darien, Conn., Teachers Publishing Corporation, 1964).

IMPORTANT IDEAS IN THIS CHAPTER

For the kindergarten, primary, and intermediate grade children, the kinds of ideas with the most meaning or application are these:

- Temperature and heat are not the same thing.
- Thermometers measure temperature.
- Materials differ in their transparency to heat energy.
- The rate at which heat travels through different materials varies.
- All materials expand when heated.
- Light rays travel in straight lines.
- Shadows are caused by an absence of light.
- White light is a mixture of different colors.
- There are two types of lenses, convex and concave.
- Heat and light energy may be converted to other forms of energy or can do work.

In the intermediate and upper grades, the children should be led to develop concepts that are more complex:

- Temperature is a measure of the average molecular motion.
- Heat is a measure of the total molecular energy.
- The angle between a mirror and the path of light from an object to the mirror is equal to the angle between the mirror and the path of light reflected from the mirror.
- When light rays pass through a prism or diffraction grating, the various frequencies (colors) are bent by different amounts.
- Light rays are refracted when they pass from one medium to another.
- The image produced by a single convex lens is inverted.

In addition to these, the Activities in this chapter should emphasize to all children the most important concept of energy—energy cannot be created or destroyed. The principle of conservation of energy, which has been reinforced throughout this book, is of primary importance in the child's understanding of energy.

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